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Best Demonstrated Available Technology (BDAT) Background Document for Cyanide Wastes (F006) (Non-CBI Version) (Proposed)

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BEST DEMONSTRATED AVAILABLE TECHNOLOGY (BDAT) BACKGROUND DOCUMENT FOR CYANIDE WASTES

(Non-CBI Version)

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1. INTRODUCTION

Pursuant to Section 3004(m) of the Resource Conservation and Recovery Act (RCRA), enacted as a part of the Hazardous and Solid Waste Amendments (HSWA) on November 8, 1984, the Environmental Protection Agency (EPA) is proposing treatment standards based on Best Demonstrated Available Technology (BDAT) for the cyanide-containing electroplating and metal heat treating wastes identified in 40 CFR 261.31 as F006, F007, F008, F009, F010, F011, F012, and F019, and for the commercial chemical product wastes identified in 40 CFR 261.33 as P013, P021, P029, P030, P063, P074, P098, P099, P104, P106, and P121. The Agency has previously established treatment standards for metals in F006 nonwastewaters with the First Third listed hazardous wastes (53 FR 31137, August 17, 1988). Treatment standards for F007, F008, F009, and F019, as well as F006 wastewater standards, were soft-hammered with the First Thirds rule. These proposed standards add an additional constituent (cyanide) to the regulated constituent list for F006 and, if finalized, supercede the soft-hammer provisions of the First Third rule for F007, F008, F009, and F019. Compliance with the final BDAT treatment standards is a prerequisite for the placement of these wastes in units designated as land disposal units according to 40 CFR Part 268.

This background document provides the Agency's technical support for selecting and developing proposed treatment standards for the constituents to be regulated for the electroplating and metal heat treating wastes. Sections 2 through 7 present information for the F-code wastes. Section 2 describes the industries affected by regulation of these wastes, explains the processes generating these wastes, and presents available waste characterization data. Section 3 specifies the applicable and demonstrated treatment technologies for these wastes and presents descriptions of those technologies. Section 4 contains performance data for the demonstrated technologies, and Section 5 analyzes these performance data to determine BDAT for each waste. In Section 6 the rationale for selection of regulated constituents is presented, and in Section 7 the proposed BDAT treatment standards are calculated for the regulated constituents selected. Section 8 discusses associated inorganic cyanide P-code wastes and details the development of the proposed treatment standards for these wastes.

EPA's promulgated methodology for developing BDAT treatment standards is described in two separate documents: Generic Quality Assurance Project Plan for Land Disposal Restriction Program ("BDAT") (USEPA 1987) and Methodology for Developing BDAT Treatment Standards (USEPA 1988c). The second document also discusses the petition process to be followed in requesting a variance from the BDAT treatment standards.

For the purpose of determining the applicability of the proposed treatment standards, wastewaters are defined as wastes containing less than 1 percent (weight basis) total suspended solids[*] and less than 1 percent (weight basis) total organic carbon (TOC). Waste not meeting this definition must comply with the proposed treatment standards for nonwastewaters.

Cyanide-containing wastes generated in metal finishing operations contain cyanide and BDAT list metals. These wastes are divided into three subcategories: the metal finishing aqueous liquids subcategory (F007, F008, F009, and F011), the metal finishing organic liquids subcategory (F010), and the metal finishing sludges subcategory (F006, F012, and F019). The following paragraph details the proposed BDAT for nonwastewaters and wastewaters for each waste subcategory. Table 1-1, at the end of this section, presents this information in tabular form.

Wet air oxidation followed by chemical precipitation and filtration is determined to be BDAT for cyanide and BDAT list metals for wastewaters for the metal finishing aqueous liquids and the metal finishing sludges subcategories. For cyanide in nonwastewaters for these two subcategories, BDAT treatment standards are based on generation of these wastes from a treatment system consisting of electrolytic oxidation followed by alkaline chlorination, chemical precipitation and sludge filtration. For metals in nonwastewaters, stabilization is determined to be BDAT for the metal finishing aqueous liquids and the metal finishing sludges. For cyanide in the metal finishing organic liquids wastes, incineration is determined to be BDAT for nonwastewaters and wet air oxidation is determined to be BDAT for wastewaters, such as scrubber water produced in incineration treatment of these wastes.

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[*] The term "total suspended solids" (TSS) clarifies EPA's previously used terminology of "total solids" and "filterable solids." Specifically, total suspended solids is measured by Method 209c. (Total Suspended Solids Dried at 103 to 105°C) in Standard Methods for the Examination of Water and Wastewater, 16th Edition (APHA, AWWA, and WPCF 1985).

For cyanide, the proposed treatment standards reflect total waste concentration. The units for the total waste concentration are mg/kg (parts per million on a weight-by-weight basis) for nonwastewaters and mg/l (parts per million on a weight-by-volume basis) for wastewaters. For BDAT list metals in nonwastewaters, the proposed treatment standards reflect the leachate concentration from the TCLP. The units for the leachate concentration are mg/l. For BDAT list metals in wastewaters, the proposed treatment standards reflect the total waste concentration, and the units are mg/l.

The proposed treatment standards for the wastewater and nonwastewater forms of the metal finishing wastes are shown in Tables 1-2 through 1-5. The P-code cyanide-containing wastes proposed for regulation contain soluble cyanide salts. These wastes are expected to be similar in characteristics to the wastes composing the metal finishing aqueous liquids subcategory; thus, the treatment standards proposed for this subcategory are also transferred to the P-code cyanide wastes. The proposed treatment standards for the P-code cyanide wastes are presented in Table 1-6. The Agency is proposing to reserve nonwastewater treatment standards for silver in P099 and P104 and for zinc in P121 because of the lack of performance data on treatment of these constituents in similar wastes by stabilization. Wastes that, as generated, contain the regulated constituents at concentrations that do not exceed the proposed treatment standards are not restricted from land disposal units.

Table 1-1 Summary of Proposed BDAT for Cyanide Waste Subcategories

Subcategory	Waste codes	Type of treatment residual	BDAT upon which proposed treatment standards are based
Metal finishing aqueous liquids	F007, F008, F009, F011	Wastewater	Wet air oxidation, chemical precipitation, polishing filtration
Metal finishing aqueous liquids	F007, F008, F009, F011	Nonwastewater	Alkaline chlorination, chemical precipitation, sludge filtration, stabilization
Metal finishing sludges	F006 (cyanide), F012, F019	Wastewater	Wet air oxidation, chemical precipitation, polishing filtration
Metal finishing sludges	F006 (cyanide), F012, F019	Nonwastewater	Alkaline chlorination, chemical precipitation, sludge filtration, stabilization
Metal finishing organic liquids	F010	Wastewater	Wet air oxidation
Metal finishing organic liquids	F010	Nonwastewater	Incineration

Table 1-2 BDAT Treatment Standards - Metal Finishing Aqueous Liquids Subcategory for F007, F008, F009, and F011

NONWASTEWATERS

Constituent	Maximum for any single grab sample Total composition (mg/kg)	TCLP (mg/l)
Cyanide (total)	110	Not applicable
Cyanide (amenable)	0.064	Not applicable
Cadmium	Not applicable	0.066
Chromium (total)	Not applicable	5.2
Lead	Not applicable	0.51
Nickel	Not applicable	0.32
Silver	Not applicable	0.072

WASTEWATERS

Constituent	Maximum for any single grab sample Total composition (mg/kg)	TCLP (mg/l)
Cyanide (total)	12	Not applicable
Cyanide (amenable)	1.3	Not applicable
Chromium (total)	0.32	Not applicable
Lead	0.04	Not applicable
Nickel	0.44	Not applicable

Table 1-3 BDAT Treatment Standards - Metal Finishing Organic Liquids Subcategory for F010

NONWASTEWATERS

Constituent	Maximum for any single grab sample Total composition (mg/kg)	TCLP (mg/l)
Cyanide (total)	1.5	Not applicable

WASTEWATERS

Constituent	Maximum for any single grab sample Total Composition (mg/kg)	TCLP (mg/l)
Cyanide (total)	12	Not applicable
Cyanide (amenable)	1.3	Not applicable

Table 1-4 BDAT Treatment Standards - Metals Finishing Sludges Subcategory for F006

NONWASTEWATERS

Constituent	Maximum for any single grab sample Total composition (mg/kg)	TCLP (mg/l)
Cyanide (total)	110	Not applicable
Cyanide (amenable)	0.064	Not applicable

WASTEWATERS

Constituent	Maximum for any single grab sample Total composition (mg/kg)	TCLP (mg/l)
Cyanide (total)	12	Not applicable
Cyanide (amenable)	1.3	Not applicable

Table 1-5 BDAT Treatment Standards - Metal Finishing Sludges Subcategory for F012 and F019

NONWASTEWATERS

Constituent	Maximum for any single grab sample Total composition (mg/kg)	TCLP (mg/l)
Cyanide (total)	110	Not applicable
Cyanide (amenable)	0.064	Not applicable
Cadmium	Not applicable	0.066
Chromium (total)	Not applicable	5.2
Lead	Not applicable	0.51
Nickel	Not applicable	0.32
Silver	Not applicable	0.072

WASTEWATERS

Constituent	Maximum for any single grab sample Total composition (mg/kg)	TCLP (mg/l)
Cyanide (total)	12	Not applicable
Cyanide (amenable)	1.3	Not applicable
Chromium (total)	0.32	Not applicable
Lead	0.04	Not applicable
Nickel	0.44	Not applicable

Table 1-6 BDAT Treatment Standards for P013, P021, P029, P030, P063, P074, P098, P099, P104, P106, and P121

NONWASTEWATERS

Constituent	Maximum for any single grab sample: Total composition (mg/kg)	Maximum for any single grab sample: TCLP (mg/l)
Cyanide (total)	110	Not applicable
Cyanide (amenable)	0.064	Not applicable
Copper (P029 only)	Not applicable	0.71
Nickel (P074 only)	Not applicable	0.30
Silver (P099 and P104 only)	Not applicable	0.07
Zinc (P121 only)	Not applicable	0.086

WASTEWATERS

Constituent	Maximum for any single grab sample: Total composition (mg/kg)	Maximum for any single grab sample: TCLP (mg/l)
Cyanide (total)	12	Not applicable
Cyanide (amenable)	1.3	Not applicable
Copper (P029 only)	0.42	Not applicable
Nickel (P074 only)	0.44	Not applicable
Silver (P099 and P104 only)	Reserved	Not applicable
Zinc (P121 only)	Reserved	Not applicable

2. INDUSTRIES AFFECTED AND WASTE CHARACTERIZATION

According to the schedule shown in 40 CFR 268.10-11, the following wastes from electroplating, metal heat treating, and chemical conversion coating operations in the metal finishing industry, defined in 40 CFR 261.31, are subject to the land disposal restriction prohibitions of RCRA:

Electroplating Operations

F006: Wastewater treatment sludges from electroplating operations except for the following processes: (1) sulfuric acid anodizing of aluminum; (2) tin plating on carbon steel; (3) zinc plating (segregated basis) on carbon steel; (4) aluminum or zinc-aluminum plating on carbon steel; (5) cleaning/stripping associated with tin, zinc, and aluminum plating on carbon steel; and (6) chemical etching and milling of aluminum.

F007: Spent cyanide plating bath solutions from electroplating operations.

F008: Plating bath residues from the bottom of plating baths from electroplating operations where cyanides are used in the process.

F009: Spent stripping and cleaning bath solutions from electroplating operations where cyanides are used in the process.

Heat Treating Operations

F010: Quenching bath residues from oil baths from metal heat treating operations where cyanides are used in the process.

F011: Spent cyanide solutions from salt bath pot cleaning from metal heat treating operations.

F012: Quenching wastewater treatment sludges from metal heat treating operations where cyanides are used in the process.

Chemical Conversion Coating Operations

F019: Wastewater treatment sludge from the chemical conversion coating of aluminum.

Section 2.1 describes the industries affected by the land disposal restrictions for F006-F012 and F019, and Section 2.2 presents descriptions of the electroplating, heat treating, and chemical conversion coating processes generating these wastes. Section 2.3 presents the available waste characterization data for these wastes. Section 2.4 discusses the Agency's rationale for dividing these wastes into three separate subcategories.

2.1 Industries Affected

The listed wastes F006, F007, F008, and F009 are generated from electroplating operations where cyanides are used in the process. The listed wastes F010, F011, and F012 are generated from metal heat treating operations where cyanides are used in the process. The listed waste F019 is generated in chemical conversion coating of aluminum.

Electroplating operations consist of the following processes: (1) common and precious metals electroplating, except tin, zinc (segregated basis),* aluminum, and zinc-aluminum plating on carbon steel; (2) anodizing, except sulfuric acid anodizing of aluminum;

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*Zinc plating (segregated basis) refers to noncyanidic zinc plating processes. For example, wastewater treatment sludges from zinc plating using baths formulated from zinc oxide and/or sodium hydroxide would be excluded from the listing, while sludges from baths formulated from zinc cyanide and/or sodium cyanide would not be excluded. Where both cyanidic and noncyanidic baths are used, the exclusion applies to sludges from the noncyanidic plating processes as long as they are segregated from sludges that result from cyanidic plating processes.

(3) chemical etching and milling, except when performed on aluminum; and (4) cleaning and stripping, except when associated with tin, zinc, and aluminum plating on carbon steel.

Heat treating operations include tempering, carburizing, carbonitriding (cyaniding), nitriding, annealing, normalizing, austenizing, austempering, quenching, siliconizing, martempering, and malleabilizing.

In the preamble to the Effluent Limitations Guidelines for the Metal Finishing Industry (48 FR 32482, July 15, 1983), the Agency identified 13,500 facilities in the metal finishing industry that use 46 electroplating and metal finishing unit operations (including electroplating, heat treating, and chemical conversion coating).

Users of electroplating and heat treating operations generally fall under Standard Industrial Classification (SIC) code series 3000, which comprises fabricated metal products except machinery and transportation equipment; machinery except electrical; electrical and electronic machinery, equipment, and supplies; transportation equipment; measuring, analyzing, and controlling instruments; and miscellaneous manufacturing industries.

2.2 Process Description

Presented in this section are descriptions of each of the four operations that EPA has included as electroplating operations: electroplating, anodizing, chemical etching and milling, and metal cleaning and stripping. Also provided are descriptions of the chemical conversion coating and metal heat treating operations.

2.2.1 Electroplating

Electroplating is the application of a thin surface coating of one metal upon another by electrodeposition. This surface coating is applied to provide corrosion protection, wear or erosion resistance, or antifrictional characteristics, or for decorative purposes. The electroplating of common metals includes the processes in which ferrous or nonferrous base material is electroplated with the following metals or metal alloys: copper, nickel, chromium, brass, bronze, zinc, tin, lead, cadmium, iron, aluminum, or combinations thereof. The alloy brass consists of copper and zinc; the alloy bronze consists of copper and tin. Precious metals electroplating includes the processes in which a ferrous or nonferrous base material is plated with gold, silver, palladium, platinum, rhodium, indium, ruthenium, iridium, osmium, or combinations thereof.

In electroplating, metal ions in acid, alkaline, or neutral solutions are reduced to the metal on negatively charged (cathodic) surfaces. The cathodic surfaces are the objects being plated. The metal ions in solution are usually replenished by the dissolution of metal from positively charged surfaces (anodes) or small pieces contained in inert wire or metal baskets. Replenishment by dissolving metal salts is also practiced, especially for chromium plating. In this case, an inert material must be selected for the anodes. Hundreds of different electroplating solutions have been adopted commercially, but only two or three types are used widely for a particular metal or alloy. For example, cyanide solutions are popular for copper, zinc, brass, cadmium, silver, and gold. However, noncyanide alkaline solutions containing pyrophosphate have come into use recently for zinc and copper. Acid sulfate solutions are also used for plating zinc, copper, tin, and nickel, especially for relatively simple shapes. Cadmium and zinc are sometimes electroplated from neutral or slightly acidic chloride solutions.

Electroplating baths contain metals, metal salts, acids, alkalies, and various bath control compounds. All of these materials contribute to the wastewater streams through dragout of bath solutions on the plated parts, through batch dumps, or through floor spills. The sludge from the bottom of plating baths also contains metals and metal salts. Table 2-1 outlines some typical electroplating bath chemical compositions.

2.2.2 Anodizing

Anodizing is an electrolytic oxidation process that converts the surface of the metal to an oxide. The oxide coatings formed in anodizing provide corrosion protection, decorative surfaces, a base for painting and other coating processes, and special electrical and mechanical properties. Aluminum is the most frequently anodized material, while some magnesium and stainless steel (electropolish) and limited amounts of zinc and titanium are also treated.

Most anodizing is carried out by the immersion of racked parts in tanks; however, some continuous anodizing is done on large coils of aluminum, in a manner similar to continuous electroplating. For aluminum

Table 2-1 Chemical Compositions of Typical Electroplating Baths

Plating compound	Constituents	Concentration in bath (g/l)
Cadmium cyanide	Cadmium oxide	22.5
	Cadmium (as metal)	19.5
	Sodium cyanide	77.9
	Sodium hydroxide	14.2
Cadmium fluoborate	Cadmium fluoborate	251.2
	Cadmium (as metal)	94.4
	Ammonium fluoborate	59.9
	Boric acid	27.0
Chromium electroplate	Chromic acid	172.3
	Sulfate	1.3
	Fluoride	0.7
Copper cyanide	Copper cyanide	26.2
	Free sodium cyanide	5.6
	Sodium carbonate	37.4
	Rochelle salt	44.9
Gold cyanide	Gold (as potassium gold cyanide)	8
	Potassium cyanide	30
	Potassium carbonate	30
	Dipotassium phosphate	30
Acid nickel	Nickel sulfate	330
	Nickel chloride	45
	Boric acid	37
Silver cyanide	Silver cyanide	35.9
	Potassium cyanide	59.9
	Potassium carbonate (min.)	15.0
	Silver (as metal)	23.8
	Free cyanide	41.2
Zinc sulfate	Zinc sulfate	374.5
	Sodium sulfate	71.5
	Magnesium sulfate	59.9

Reference: USEPA 1980.

parts, the formation of the oxide occurs when the parts are made anodic in dilute sulfuric acid or dilute chromic acid solutions. The oxide layer begins formation at the outer surface of the base metal, and as the reaction proceeds, the oxide grows into the metal. The oxide formed last, known as the boundary layer, is located at the interface between the base metal and the oxide. The boundary is extremely thin and nonporous. Chromic acid anodic coatings are more protective than sulfuric acid coatings and have a relatively thick boundary layer.

2.2.3 Chemical Etching and Milling

These processes are used to produce specific design configurations and tolerances or surface appearances on parts by controlled dissolution of the base metal with chemical etchants. Included in this classification are the processes of chemical milling, chemical etching, and bright dipping. Chemical etching is the same process as chemical milling, but the rates and depths of metal removal are usually much greater in chemical milling. Typical solutions for chemical milling and etching include solutions of ferric chloride, nitric acid, ammonium persulfate, chromic acid, cupric chloride, hydrochloric acid, and combinations of these etchants. Bright dipping is a specialized form of etching that is used to remove oxide and tarnish from ferrous and nonferrous materials and is frequently performed just prior to plating. Bright dipping solutions are usually composed of mixtures of two or more of the following acids: sulfuric, chromic, phosphoric, nitric, and hydrochloric.

2.2.4 Metal Cleaning and Stripping

Metal cleaning operations are designed to prepare metal surfaces for electroplating by removing oil, grease, dirt, and metal oxides, using water with or without a detergent or other dispersing agent. Cleaning can be done with alkaline (either electrolytically or nonelectrolytically), neutral, or acidic solutions. Nonelectrolytic cleaning, using both alkaline and acid solutions, can be done by either soak or spray methods. Acid cleaning can be referred to as pickling. Effective cleaning is also accomplished by alkaline electrolytic cleaning, or electrocleaning. Electrocleaning can be run cathodically (with the workpiece as the cathode), anodically (with the workpiece as the anode), or in periodic reversal (PR) mode, in which the current is periodically reversed from cathodic to anodic. Cleaning baths eventually become contaminated with metals derived from the cleaned parts.

Metal stripping is the chemical removal of metal plating coatings from base metal products by immersion of the plated part in an aqueous bath of appropriate chemical composition. When a plated coating on a part does not meet product quality specifications, it may be more economical to remove the metal plating and reuse the part than to scrap the entire plated part. Stripping baths can contain strong alkaline solutions of cyanide salts (to strip copper plating from steel parts, for instance) or strong acids. The stripping solution dissolves the plated coating, leaving the base metal essentially untouched.

2.2.5 Chemical Conversion Coating

The conversion coating operation includes processes such as chromating, phosphating, metal coloring, and passivating. In chromating, a portion of the base metal is converted to a protective film formed by the coating solution. Aqueous solutions containing hexavalent chromium and other active organic or inorganic compounds are used. Chromate coatings are most frequently applied to aluminum, magnesium, cadmium, copper, brass, bronze, silver, and zinc.

Phosphating and coloring involve formation of surface metallic phosphates, oxides, or other compounds that impart a color to the metal while also forming a protective coating. Passivating is the formation of a protective film on metals, particularly stainless steel and copper, by immersion in an acid solution. Coloring is the only one of these three operations that may sometimes be used on aluminum.

2.2.6 Heat Treating

Heat treating is the modification of the physical properties of a metal piece through the application of controlled heating and cooling cycles. Heat treating is most frequently accomplished by placing the metal parts in an atmosphere (air or other gases) at the appropriate temperatures for the appropriate period of time. Heat treating can also be accomplished by placing parts (usually small items) in molten salt baths, including baths using cyanide salts. After immersion in the salt bath, parts are removed and cooled in either a water or an oil bath or in air.

Heat treating may be used to develop a surface coating on the metal or to change the physical properties of the bulk metal. Cyanides are most often used in the heat treating operations of carburizing, carbonitriding, and nitriding, which add carbon, nitrogen, or both to the surface of the metal to form a hard surface coating.

2.3 Waste Characterization

This section summarizes the waste characterization data available to the Agency for the F006 through F012 and F019 wastes. The major constituents in the wastes and their approximate concentrations are presented in Table 2-2, which is based on the available waste characterization data summarized in Appendix B. Tables B-1 through B-8 in Appendix B present, by waste code, the concentration for BDAT list constituents and other parameters identified for the specific wastes. These data were obtained from a variety of sources, as referenced in the tables, including literature sources and EPA sampling and analysis.

The metal finishing industry wastes are divided into three distinct groups based on the process generating the waste and the waste composition. F007, F008, F009, and F011 wastes generally contain from 1 percent cyanide (or approximately 2 percent, as NaCN) up to 15 percent cyanide. These wastes also often contain dissolved metals (especially F007, F008, and F009, which typically contain approximately 2 percent BDAT metals) and must be treated for metals removal by chemical precipitation. F010 wastes may contain high concentrations of oil and grease, as well as cyanide concentrations similar to those of the first group. F006, F012, and F019 are wastewater treatment sludges typically

Table 2-2 Summary of Waste Composition Data for F006-F012 and F019 Wastes

Constituent/parameter	Concentration (percent) F006	F007	F008	F009
Cyanide (as NaCN)	<0.1-0.5	5-10	2-10	5-20
BDAT Metals				
Cadmium	0-2	0-2	0-2	0-2
Chromium	0-30	<0.1	<0.1	<0.1
Copper	0-3	0-1	0-2	0-2
Lead	0-3	<0.1	<0.1	<0.1
Nickel	0-17	0-2	0-2	0-2
Zinc	0-9	0-2	0-2	<0.1
TOTAL BDAT METALS	<0.1-30	-2	-2	-2
BDAT organics	<0.1	<0.1	<0.1	<0.1
Non-BDAT Inorganics (primarily sodium carbonate, iron, calcium hydroxide)	20-40	20-40	35-40	20
Water	30-80	55-70	55	60-73
Oil and grease	0-4	<0.1	<0.1	<0.1

Constituent/parameter	Concentration (percent) F010	F011	F012	F019
Cyanide (as NaCN)	1-4	3-20	<0.1-12	<0.1-0.8
BDAT Metals				
Cadmium	-	<0.1	<0.1	<0.1
Chromium	-	<0.1	<0.1	<0.1-10
Copper	-	<0.1	<0.1	<0.1
Lead	-	<0.1	<0.1	<0.1
Nickel	-	<0.1	<0.1	<0.1
Zinc	-	<0.1	<0.1	<0.1
TOTAL BDAT METALS	<1	0.2	0.1	<0.1-10
BDAT Organics	<0.1	<0.1	<0.1	<0.1
Non-BDAT Inorganics (primarily sodium carbonate, iron, calcium hydroxide)	1-99	20-80	28-40	30-40
Water	0	0-77	60	60
Oil and grease	1-99	<0.1	<0.1	<0.1

- = Not available

containing less than 1 percent metals in a hydroxide or sulfide sludge. These wastes may contain 5 percent or more cyanide (i.e., 10 percent cyanide (as NaCN) in Table 2-2) but typically contain less than 1,000 ppm cyanide.

F006 through F012 and F019 wastes contain BDAT metals and cyanides, as well as other inorganic compounds and water. The concentrations of individual metals in F007, F008, and F009 wastes are dependent on the type of electroplating solutions used at the particular facility generating the waste. Additionally, F007 through F009, F012, and F019 may contain low concentrations of volatile and semivolatile organic compounds as contaminants.

The Agency wishes to emphasize that sludges generated from treatment of spent cyanide plating baths may also be classified as F006. An example is a wastewater treatment sludge generated from treatment of a spent cyanide plating solution (an F007 wastewater). This bath solution may be sent through cyanide destruction and chemical precipitation for metals removal separately from other wastewaters. In this case, the precipitated residual would be F007. If the F007 waste were combined with other plant wastes (such as the listed wastes F008 or F009 or electroplating rinsewaters) before cyanide destruction and chemical precipitation treatment in a wastewater treatment system, then the precipitated residual from this treatment would be F006.

2.4 Determination of Waste Subcategories

In cases where EPA believes that constituents present in different waste codes can be treated to similar concentrations using the same treatment technologies, the Agency may combine the codes into a single subcategory.

Based on review of the processes generating the electroplating and metal heat treating wastes and all available data characterizing these wastes, the Agency has determined that these wastes represent three separate waste subcategories. The first subcategory, the metal finishing aqueous liquids subcategory, contains the inorganic electroplating and metal heat treating wastes that are likely to contain high concentrations of cyanide salts (F007, F008, F009, and F011). These wastes also may require treatment by chemical precipitation for dissolved metals removal. Treatment of these wastes results in generation of wastewater treatment sludges that are similar to the listed wastes F006 and F012.

The second subcategory, the metal finishing sludges subcategory, contains the wastes that are characterized as wastewater treatment sludges (F006, F012, F019). The BDAT metals in these wastes are present in a relatively insoluble form and consequently do not require further treatment by chemical precipitation (which is used to treat dissolved metals). These residual wastes (F006, F012, F019) also may not require treatment of cyanide by a cyanide destruction technology (e.g., alkaline chlorination or wet air oxidation) if the wastewaters were treated properly for cyanide in the wastewater treatment process that generated the F006, F012, or F019 wastes. These wastes usually contain cyanides in lower concentrations than those in the wastes in the first group.

The third subcategory is the metal finishing organic liquids subcategory, which contains the waste code F010. F010 is typically generated with a high oil and grease content (a constituent that has been identified as a waste characteristic affecting treatment performance) and little or no water, and thus requires a treatment technology that can treat for cyanides in a waste matrix that contains a high concentration of oil and grease.

Although the concentrations of specific constituents will vary from waste code to waste code within each subcategory identified, all of the wastes within each subcategory contain similar constituents that are expected to be treatable to similar concentrations using the same technologies. EPA will therefore propose BDAT treatment standards that are applicable to all wastes in each subcategory.

3. APPLICABLE AND DEMONSTRATED TREATMENT TECHNOLOGIES

Section 2 established three subcategories for F006-F012 and F019 wastes. This section identifies the treatment technologies that are applicable to these subcategories and determines which, if any, of the applicable technologies can be considered demonstrated for the purposes of establishing BDAT.

To be applicable, a technology must be theoretically usable to treat the waste in question or to treat a waste that is similar in terms of the parameters that affect treatment selection. To be demonstrated, the technology must be employed in full-scale operation for the treatment of the waste in question or a similar waste. Technologies that are available only at research facilities or at pilot- and bench-scale operations are not considered demonstrated technologies for the purpose of identifying BDAT.

Also in this section, the Agency has provided a description of each of the applicable technologies for cyanide-containing wastes. A description of other treatment technologies can be found in EPA's Treatment Technology Background Document.

3.1 Applicable Treatment Technologies

3.1.1 Metal Finishing Aqueous Liquids Subcategory

EPA has identified four technologies as potentially applicable for treatment of cyanides in the metal finishing aqueous liquids subcategory (F007, F008, F009, and F011 wastes): (1) electrolytic oxidation; (2) chemical oxidation with several oxidizing agents, such as hypochlorite or chlorine (alkaline chlorination), permanganate, ozone, or SO_2/air (INCO process); (3) wet air oxidation; and (4) high-temperature cyanide hydrolysis. Each of these may be followed by chemical precipitation, filtration, and sludge dewatering for metals removal.

Electrolytic oxidation followed by alkaline chlorination, chemical oxidation (alkaline chlorination or other methods) alone, electrolytic oxidation alone, wet air oxidation, and high-temperature hydrolysis, reduce the concentration of cyanide in the wastewaters or nonwastewaters treated. Chemical precipitation treatment of the wastewater residual from cyanide oxidation, followed by filtration of the treated wastewater and dewatering of the precipitated solids, reduces the concentration of metals in the wastewater and concentrates the metals in the treatment sludge in a relatively insoluble form. Filtration and dewatering may also concentrate cyanide in the treatment sludge residual. The treatment sludge metal constituents may then require further treatment by the applicable nonwastewater treatment technologies specified below for the wastes F006, F012, and F019.

3.1.2 Metal Finishing Sludges Subcategory

EPA has identified three technologies as potentially applicable for treatment of the wastewater treatment sludges in the metal finishing sludges subcategory (F006, F012, and F019): stabilization, vitrification, and high temperature metals recovery. The first two technologies are designed to reduce the leachability of the metals; the third reduces both the total concentration and the leachability of the metals. Treatment standards for the metal constituents in F006 nonwastewaters have been developed with the First Third of RCRA listed hazardous wastes (see 53 FR 31137, August 17, 1988) and thus are not discussed here.

Stabilization may chemically reduce the mobility of metal constituents in a waste. Stabilizing agents, binders, and chemicals are added to a waste to minimize the quantities of metals that leach when the waste is in contact with water. Commonly used stabilization agents include portland cement, lime/pozzolan-based material, and cement kiln dust.

The Agency does not believe that stabilization is an applicable technology for the treatment of amenable or complexed cyanide constituents in hazardous wastes. The Agency believes that stabilization only reduces the leachability of constituents but does not destroy the constituents. Furthermore, the Agency believes that stabilization is suited primarily for stabilizing cationic species (such as some of the BDAT metals); therefore, it does not effectively stabilize anionic species (such as cyanides).

Vitrification has also been identified by the Agency as an applicable technology. A vitrification process can be used to immobilize hazardous constituents in F012 or F019 waste by producing a vitreous or glass-like mass.

EPA has also identified high temperature metals recovery technologies as applicable. High temperature metals recovery technologies reduce the concentration of some metals in the waste through volatilization and recovery of the volatilized metals and/or the metals remaining in the residual. High temperature metals recovery treatment results in a residual (or slag) that may be land disposed.

3.1.3 Metal Finishing Organic Liquids Subcategory

EPA has identified incineration as an applicable technology for treatment of wastes in the metal finishing organic liquids subcategory (F010). Incineration is a thermal treatment process that destroys the organic and oxidizable inorganic waste constituents. Incineration of this waste generates an ash and a scrubber water that may require further treatment. Phone contacts with generators of F010 wastes indicate that these wastes may also be treated by an oil/water separation step, followed by recycling of the oil phase and treatment of the inorganic phase by one of the other cyanide destruction technologies discussed above.

3.2 Demonstrated Treatment Technologies

Available information shows that electrolytic oxidation followed by alkaline chlorination, alkaline chlorination alone, wet air oxidation, high temperature hydrolysis, and SO_2/air oxidation are demonstrated for treatment of cyanide in F007, F008, F009, and F011 wastes. The Agency has identified at least one full-scale facility that uses electrolytic oxidation followed by alkaline chlorination to treat cyanide in F011 waste, at least five facilities that use alkaline chlorination to treat cyanide in F007-F009 or F011 wastes, at least one facility that treats cyanide-containing wastes by high temperature cyanide hydrolysis, and one pilot-scale facility that has treated F007 waste by wet air oxidation.

In addition, wet air oxidation and SO_2/air oxidation are used to treat similar wastes in full-scale processes. EPA believes that chemical precipitation followed by filtration and sludge dewatering is demonstrated at many facilities for treatment of BDAT metals on these wastes and similar wastes (such as K062, which was regulated with the First Third of the RCRA-listed hazardous wastes).

Available information also shows that all of the applicable technologies for treatment of BDAT metals in F012 and F019 wastes are demonstrated. The characteristics of F012 and F019 wastes (high solids content, substantial concentrations of BDAT metals, very low concentrations of oil and grease and BDAT organic constituents) would allow these wastes to be treated by the same methods used for F006. Stabilization is used by at least ten facilities to treat F006 wastes. EPA knows of two full-scale facilities that use metals recovery for F006 wastes and one full-scale facility that treats F006 waste by vitrification.

The Agency also believes that incineration is demonstrated for treatment of metal finishing organics liquids (F010). The Agency is aware of at least one full-scale facility that has treated F010 and similar wastes by incineration.

3.3 Descriptions of Cyanide Treatment Technologies

3.3.1 Electrolytic Oxidation

(1) Applicability

Electrolytic oxidation is a treatment process that is applicable to treatment of wastes containing high concentrations of cyanide in solution. Because of excessive retention time requirements, the process is often applied as preliminary treatment for highly concentrated cyanide wastes, prior to more conventional chemical cyanide oxidation (Cushnie 1985).

This treatment technology is used in industry for the destruction of cyanide in (a) concentrated spent plating solutions and stripping solutions, (b) spent heat treating baths, (c) alkaline descalers, and (d) metal passivating (rust inhibiting) solutions. Electrolytic oxidation has been demonstrated successfully for treatment of wastes containing concentrations of cyanide up to 100,000 mg/l (Easton 1967). For concentrations of cyanide lower than 500 mg/l, chemical oxidation treatment may be more efficient.

(2) Underlying Principles of Operation

The underlying principle of electrolytic oxidation of cyanide is that the concentrated cyanide waste is subject to an electrolytic reaction with dissolved oxygen in aqueous solution and is broken down to the gaseous products carbon dioxide (CO_2), nitrogen (N_2), and ammonia (NH_3). The process is conducted at elevated temperatures for periods ranging from several hours to over a week, depending on the initial cyanide concentration and the final cyanide concentration required. The theoretical destruction process that takes place at the anodes is described by the following reaction:

$$\underset{\text{cyanide ion}}{2CN^-} + \underset{\text{oxygen}}{2O_2} \xrightarrow{\text{Electricity}} \underset{\text{carbon dioxide}}{2CO_2} + \underset{\text{nitrogen}}{N_2} + \underset{\text{electrons}}{2e^-}$$

The effectiveness of electrolytic oxidation is dependent on the conductivity of the waste, which is a function of several waste characteristics including the concentration of cyanide and other ions in solution. As the process continues, the waste becomes less capable of conducting electricity as cyanide concentration is reduced, causing the electrolytic reaction to be much less efficient at longer retention times.

(3) Physical Description of the Electrolytic Oxidation Process

Normally, electrolytic destruction of cyanide takes place in a closed cell. This cell consists of two electrodes suspended in an aqueous solution, with direct current (DC) electricity supplied to drive the reaction to completion. The temperature of the bath containing the cyanide waste should be maintained at or above 52°C (125°F). Sodium chloride may be added to the solution as an electrolyte (conductor) to increase the conductivity of the waste being treated. Since the reaction may take days or weeks, water is usually added to the tank periodically to make up for losses due to evaporation from the heated tank. This is necessary to ensure that the electrodes remain fully submerged so that a full flow of current is maintained in the solution during treatment.

(4) Waste Characteristics Affecting Performance (WCAPs)

In determining whether performance standards can be transferred to an untested waste from a previously tested waste, EPA will examine the following waste characteristics: (a) concentration of other oxidizable materials and (b) concentration of metals.

(a) Concentration of oxidizable materials. The presence of oxidizable organics (such as oil and grease and surfactants) and the presence of inorganic ionic species in a reduced state (such as trivalent chromium or sulfide) may increase the treatment time required to achieve destruction of cyanide. High concentrations of these materials may be oxidized preferentially to the cyanide in solution. If high concentrations of other oxidizable materials, such as oil and grease and surfactants, are present in the untreated waste, then the treatment of the waste may require more reaction time than for a waste of equivalent cyanide concentration and much lower concentrations of other oxidizable materials to achieve the same treatment performance.

(b) Concentration of metals. The electrolytic process may cause some of the more easily reduced metals in the waste, such as copper, to plate out onto the anode as the pure metal. While plating of metals should not have a major adverse effect on the cyanide destruction process, it may result in changes in current density and, hence, may change the rate of cyanide oxidation. This factor should be taken into account when retention time is determined.

(5) Design and Operating Parameters

EPA's analysis of whether an electrolytic cyanide destruction system is well designed and well operated will focus on the following parameters: (a) temperature, (b) reaction time, (c) pH, (d) electrical conductivity, (e) electrode spacing and surface area, and (f) mixing.

(a) Temperature. For the electrolytic process, elevated temperatures are used. Normal temperatures range from 52° to 93°C (125° to 200°F) and are measured by thermocouples in the reaction tank and read from gauges or digital readouts. The temperature can be raised by increasing the flow of steam to the coils or jacket supplying heat to the reactor contents.

(b) Reaction time. Electrolytic oxidation is usually a batch process. The time allowed to complete the reaction is an important factor in electrolysis and is dependent on the initial concentration of the waste and the desired final cyanide concentration. The rate of cyanide destruction decreases as the cyanide concentration decreases (i.e., the rate of cyanide destruction asymptotically approaches zero). Typical reaction times range from periods of several hours to more than a week. Retention time in a batch process is based on initial and final concentrations of cyanide in the waste. This parameter will be monitored by EPA and compared to the desired design value.

(c) pH. Typical solutions for electrolytic oxidation have a pH ranging from 11.5 to 12.0. The pH must be maintained in the alkaline range to prevent liberation of toxic hydrogen cyanide. Typically, pH is controlled by the addition of caustic or lime. The pH is monitored periodically during the treatment by probes and analog or digital readouts.

(d) Electrical Conductivity. The solution must have a high enough electrical conductivity to allow the reaction to proceed at an acceptable rate. If the conductivity is not high enough, it can be improved by adding an electrolyte such as sodium chloride. The conductivity of the waste during the reaction is normally determined by monitoring both the current and voltage of the cell.

(e) Electrode spacing and surface area. The spacing and surface area of the electrodes directly impact the current flowing through the waste. The reaction rate is increased by closer electrode spacing and more electrode surface area because of increased current density.

(f) Mixing. Electrolytic destruction of cyanide requires good mixing of the reaction vessel. Mixing helps ensure an adequate supply of oxygen (from the air) for the electrochemical reaction (see Underlying Principles of Operation), enhances mass transfer to promote the oxidation reaction, and keeps suspended solids in suspension. Mixing may be provided by the bubbling of air from the bottom of the reactor or by an external source of mixing may be provided.

3.3.2 Chemical Oxidation

(1) Applicability

Chemical oxidation processes are used to oxidize a number of BDAT list organic compounds, including phenol and some substituted phenols. In addition, they are used to treat sulfide wastes by converting the sulfide to sulfate. Also, the destruction of cyanides in wastes generated from industrial processes using cyanides can be accomplished by chemical oxidation. Chemical oxidation of cyanide is applicable for dissolved cyanides in aqueous solutions, such as wastewaters from metal plating and finishing operations, or for inorganic sludges from these operations that contain soluble cyanide compounds. Chemical oxidation is most applicable to cyanides that are in a form that can be easily disassociated in water to yield free cyanide ions. If the cyanide is present in water as a tightly bound complex ion (e.g., ferrocyanide), then chemical oxidation will treat the cyanide only to a limited extent.

Chemical oxidation may also be used in treatment of complexed metal wastes. Organic compounds such as EDTA, NTA, citric acid, glutaric acid, lactic acid, and tartrates are often used as chelating agents to prevent metal ions from precipitating out in electroless plating solutions. When these spent plating solutions require treatment for metals removal by chemical precipitation, the organic chelating agents must first be destroyed. Chemical oxidants, potassium permanganate in particular, are effective in releasing metals from complexes with these organic compounds (Schroeter and Painter 1987).

(2) Underlying Principles of Operation

Inorganic cyanides, some dissolved organic compounds, and sulfides can be chemically oxidized to yield carbon dioxide, water, salts, simple organic acids, and, in the case of sulfides, sulfates. The principal chemical oxidants used are hypochlorite, chlorine gas, chlorine dioxide, hydrogen peroxide, ozone, and potassium permanganate. The reaction chemistry for each is discussed below.

(a) Oxidation with hypochlorite or chlorine (alkaline chlorination). This type of oxidation is carried out using sodium hypochlorite (NaOCl), calcium hypochlorite ($Ca(OCl)_2$), chlorine gas (Cl_2), or sometimes chlorine dioxide gas (ClO_2). The reactions are normally conducted under slightly or moderately alkaline conditions. For example, alkaline chlorination of cyanide is a two-step process usually operated at a pH of 10-11.5 for the first step and 8.5 for the second step. Cyanogen chloride (CNCl) is formed as a reaction intermediate in the first step of this reaction. Example reactions for the oxidation of cyanide, phenol, and sulfide using sodium hypochlorite are shown below:

Cyanide: $CN^- + NaOCl \rightarrow OCN^- + NaCl$ (Step 1)

$2OCN^- + 3NaOCl \rightarrow CO_3^{2-} + CO_2 + N_2 + 3NaCl$ (Step 2)

Phenol: $C_6H_5OH + 14NaOCl \rightarrow 6CO_2 + 3H_2O + 14NaCl$

Sulfide: $S^= + 4NaOCl \rightarrow SO_4^= + 4NaCl$

Chlorine dioxide also oxidizes the same pollutants under identical conditions. Chlorine dioxide first hydrolyzes to form a mixture of chlorous ($HClO_2$) and chloric ($HClO_3$) acids. These act as the oxidants, as shown in the equations below, for phenol:

$$2ClO_2 + H_2O \rightarrow HClO_2 + HClO_3$$

$$C_6H_5OH + 7HClO_2 \rightarrow 6CO_2 + 3H_2O + 7HCl$$

$$3C_6H_5OH + 14HClO_3 \rightarrow 8CO_2 + 9H_2O + 14HCl$$

(b) Peroxide Oxidation. Peroxide oxidizes the same constituents alkaline chlorination oxidizes under similar conditions. The relevant reactions are:

Sulfide: $S^= + 4H_2O_2 \rightarrow SO_4^= + 4H_2O$

Phenol: $C_6H_5OH + 14H_2O_2 \rightarrow 6CO_2 + 17H_2O$

(c) Oxidation with ozone (ozonation). Ozone is an effective oxidizing agent for treatment of organic compounds and for the oxidation of cyanide to cyanate. Cyanogen gas (C_2N_2) is a reaction intermediate in this reaction. Further oxidation of cyanate to carbon dioxide and nitrogen compounds (N_2 or NH_3) occurs slowly with ozone. The oxidation of cyanide to cyanate proceeds by the following reaction:

$$CN^- + O_3 \rightarrow CNO^- + O_2$$

The rates of ozonation reactions can be accelerated by supplying ultraviolet (UV) radiation during treatment. Some literature sources indicate that, for even the most difficult cyanide complexes to treat -- the iron-cyanide complexes -- cyanide can be oxidized completely.

(d) Oxidation with potassium permanganate. Potassium permanganate can also be used to oxidize the same constituents as the other chemical oxidents. The reaction of potassium permanganate with phenol at an acidic pH and with cyanide at pH 12 to 14 are as follows:

Phenol: $3C_6H_5OH + 28KMnO_4 + 28H^+ \rightarrow 18CO_2 + 28MnO_2 + 23H_2O + 28K^+$

Cyanide: $CN^- + 2KMnO_4 + Ca(OH)_2 \rightarrow CNO^- + K_2MnO_4 + CaMnO_4 + H_2O$

In cyanide oxidation using potassium permanganate, cyanide is oxidized only to cyanate. Further oxidation of cyanate can be accomplished by acid hydrolysis or by the use of a different oxidizing agent.

(e) SO_2/air oxidation. Cyanide can be oxidized to cyanate in aqueous solution by bubbling air containing from 1 to 10 percent SO_2 through the waste. The SO_2 is also oxidized to sulfate in this reaction. This treatment process occurs by the following reaction:

$$CN^- + SO_2 + O_2 + H_2O \rightarrow CNO^- + H_2SO_4$$

This oxidation reaction requires the use of a soluble copper salt catalyst. Copper sulfate ($CuSO_4$) is most often used. SO_2/air is used frequently in the treatment of wastewaters from gold production, which contain both cyanide and thiocyanate, because SO_2/air does not oxidize thiocyanate as strongly as cyanide. Alkaline chlorination and other common oxidizing agents oxidize thiocyanate more strongly than cyanide. As with potassium permanganate, further oxidation of cyanate does not occur with SO_2/air.

(3) Description of Chemical Oxidation Processes

(a) Alkaline chlorination. Alkaline chlorination can be accomplished by either batch or continuous processes. For batch treatment, the wastewater is transferred to a reaction tank, where the pH is adjusted and the oxidizing agent is added. In some cases, the tank may be heated to increase the reaction rate. For oxidation of most compounds, a slightly to moderately alkaline pH is used. It is important that the tank be well mixed for effective treatment to occur. After treatment, the wastewater is either directly discharged or transferred to another process for further treatment.

In the continuous process, automatic instrumentation is used to control pH, reagent addition, and temperature. An oxidation-reduction potential (ORP) sensor is usually used to measure the extent of reaction.

(b) Peroxide oxidation. The peroxide oxidation process is run under similar conditions and with similar equipment to those used in the alkaline chlorination process. Hydrogen peroxide solution is added as a liquid, a step similar to that used for sodium or calcium hypochlorite.

(c) Ozonation. Ozonation can be conducted as a batch process or a continuous process. The ozone for treatment is produced onsite because of the hazards of transporting and storing ozone as well as its short shelf life. The ozone gas is supplied to the reaction vessels by injection into the wastewater. The batch process uses a single reaction tank. As with alkaline chlorination, the amount of ozone added and the reaction time used are determined by the type and concentration of the oxidizable contaminants, and vigorous mixing should be provided for complete oxidation.

In continuous operation, two separate tanks may be used for reaction. The first tank receives an excess dosage of ozone. Any excess ozone remaining at the outlet of the second tank is recycled to the first tank, thus ensuring that an excess of ozone is maintained and also that no ozone is released to the atmosphere. As with alkaline chlorination, an ORP control system is usually necessary to ensure that sufficient ozone is being added.

(d) Permanganate oxidation. Permanganate oxidation is conducted in tanks, in a manner similar to that used in alkaline chlorination as discussed previously. Potassium permanganate is normally dissolved in an auxiliary tank and added as a solution. As with the other oxidizing agents, ORP (for continuous processes) and excess oxidizing agent (for batch processes) are monitored to measure the extent of reaction.

(e) SO_2/air oxidation. SO_2/air oxidation of cyanide depends on efficient mixing of air with the waste to ensure an adequate supply of oxygen. Because of this factor, the equipment requirements for this process are similar to those of ozonation. SO_2 is sometimes supplied with the air by using flue gas containing SO_2 as the air source. Otherwise, sulfur in the +4 oxidation state can be fed as gaseous sulfur dioxide (SO_2), liquid sulfurous acid (H_2SO_3), sodium sulfite (Na_2SO_3) solution, or sodium bisulfite ($NaHSO_3$) solution. Sodium bisulfite solution, made by dissolving sodium metabisulfite ($Na_2S_2O_5$) in water, is the most frequently used source of SO_2. This process is usually run continuously, with the addition of oxidizing agent and acid/alkali being controlled through continuous monitoring of ORP and pH, respectively.

(4) Waste Characteristics Affecting Performance (WCAPs)

In determining whether performance standards can be transferred to an untested waste from a previously tested waste, EPA will examine the following waste characteristics: (a) the concentration of other oxidizable contaminants and (b) the concentration of metal salts.

(a) Concentration of other oxidizable compounds. The presence of other oxidizable compounds in addition to the BDAT constituents of concern will increase the demand for oxidizing agents and hence potentially reduce the effectiveness of the treatment process. As a surrogate for the amount of oxidizable organics present, EPA will analyze for total organic carbon (TOC). A TOC concentration in the untreated waste that is significantly higher than the concentration of the BDAT constituent(s) of concern is an indication that the addition of excess oxidizing agent will be required in order to effectively treat the waste. Inorganic reducing compounds such as sulfide may also create a demand for additional oxidizing agent; EPA will also attempt to identify and analyze for these constituents.

(b) Concentration of metal salts. Metal salts, especially lead and silver salts, will react with the oxidizing agent(s) to form metal peroxides, chlorides, hypochlorites, and/or chlorates. These reactions can cause an excessive consumption of oxidizing agents and potentially interfere with the effectiveness of treatment.

An additional problem with metals in cyanide solutions is that metal-cyanide complexes are sometimes formed. These complexes are negatively charged metal-cyanide ions that are extremely soluble.

Cyanide in the complexed form may not be oxidizable, depending on the strength of the metal-cyanide bond in the complex and the type of oxidizing agent used. Iron complexes (for example, the ferrocyanide ion, $Fe(CN)_6^{-4}$) are the most stable of the complexed cyanides.

(5) Design and Operating Parameters

In assessing the effectiveness of the design and operation of a chemical oxidation system, the Agency will examine the following parameters: (a) retention time, (b) type of oxidizing agent and rate and/or amount of addition, (c) mixing, (d) pH, (e) temperature, and (f) addition of catalyst.

(a) Retention time. The system must be designed to provide enough retention time to ensure complete oxidation. For a batch system, adequate retention time is provided by holding the treated batch until the reaction nears completion. The retention time can be easily varied from batch to batch depending on the concentration of contaminants in the untreated waste. The rate of reaction can be increased somewhat by increasing the temperature if the reaction tank is equipped with heating units. For continuous systems, retention time is determined by the size of the tank and the influent flow rate of waste treated. To ensure that the system is operated at the design retention time, EPA will monitor the waste feed rate for continuous processes.

(b) Amount and type of oxidizing agent. Several factors influence the choice of oxidizing agents and the amount to be added. The amount of oxidizing agent required to treat a given amount of the oxidizable constituent(s) will vary with the agent chosen. Enough oxidant must be added to ensure complete oxidation; the specific amount will depend on the type of oxidizable compounds in the waste and the chemistry of the oxidation reactions. Theoretically, the amount of oxidizing agent to be added can be computed from oxidation reaction stoichiometry; in practice, an excess of oxidant should be used. Testing for excess oxidizing agent will determine whether the reaction has reached completion. In continuous processes, the addition of oxidizing agent is accomplished by automated feed methods. The amount of oxidizing agent needed is usually measured and controlled automatically by an oxidation-reduction potential (ORP) sensor. In assessing the effectiveness of any chemical oxidation system, EPA would want to know how a facility determines the amount of oxidant to be added and, for continuous processes, how the facility ensures that the particular addition rate is maintained. EPA would also test for excess oxidizing agent for batch processes and monitor the ORP for continuous processes to ensure that excess oxidizing agent is supplied.

If ozone, chlorine gas, or other gaseous oxidizing agents are used, the gas must be supplied to the reaction vessel in a manner that maximizes contact between the gas and the waste.

(c) Mixing. Process tanks must be equipped with mixers to ensure maximum contact between the oxidizing agent and the waste solution. Proper mixing also limits the production of any solid precipitates from side reactions that may resist oxidation. Mixing also provides an even distribution of tank contents and a homogeneous pH throughout the waste, improving oxidation of wastewater constituents. The quantifiable degree of mixing is a complex assessment that includes, among other things, the amount of energy supplied, the length of time the material is mixed, and the related turbulence effects of the specific size and shape of the tank. This is beyond the scope of simple measurement. EPA will, however, evaluate the degree of mixing qualitatively by considering whether mixing is provided and whether the type of mixing device is one that could be expected to achieve uniform mixing of the waste solution.

(d) pH. Operation at the optimal pH will maximize the chemical oxidation reactions and may, depending on the oxidizing agent being used, limit the formation of undesirable reaction byproducts or the escape of cyanide from solution as HCN gas. The pH in batch processes should be monitored at regular intervals during the reaction. The pH is controlled by the addition of caustic, lime, or acid to the solution. In most cases, a slightly or moderately alkaline pH is used, depending on the type of oxidizing agent being used and the compound being treated (see Underlying Principles of Operation). In alkaline chlorination treatment of organics, a slightly acidic pH may be selected as an optimum. In permanganate oxidation, a pH of 2 to 4 is often selected. To ensure that the proper pH is maintained during treatment, EPA will monitor the pH.

(e) Temperature. Temperature is important because it affects the rate of reaction and the solubility of the oxidizing agent in the waste. As the temperature is increased, the solubility of the oxidizing agent will, in most instances, be increased; thus the required reaction time will, in most cases, be reduced. EPA will monitor the temperature during the treatment period to ensure that the design value is achieved.

(f) Addition of catalyst. Adding a catalyst that promotes oxygen transfer and thus enhances oxidation has the effect of lowering the necessary reactor temperature and/or improving the level of destruction of oxidizable compounds. For waste constituents that are more difficult to oxidize, catalyst addition may be necessary to effectively destroy the constituent of concern. Catalysts typically used for this purpose include copper bromide and copper nitrate. If a catalyst is required, EPA will monitor the type, quantity, and method of addition of the catalyst.

3.3.3 Wet Air Oxidation

(1) Applicability

The wet air oxidation process, the aqueous phase oxidation of dissolved or suspended organic substances or other hazardous compounds at elevated temperatures and pressures, has been developed and commercialized within the past 15 years, primarily as a less expensive alternative to other types of chemical oxidation processes.

Wet air oxidation is used to treat aqueous wastes that contain certain BDAT list organics and oxidizable inorganics such as cyanide. The process has typically been used to oxidize sewage sludge, regenerate spent activated carbon, and treat process wastewaters. Wastewaters treated include pesticide wastes, petrochemical process wastes, cyanide-containing metal finishing wastes, spent caustic wastewaters containing phenolic compounds, and some organic chemical production wastewaters.

This technology differs from the treatment technologies generally used to treat wastewaters containing organics in several aspects. First, wet air oxidation can be used to treat wastewaters that have higher organic concentrations than are normally handled by biological treatment or carbon adsorption but may be too dilute to be effectively treated by thermal processes such as incineration. Wet air oxidation is most applicable for waste streams containing dissolved or suspended organics in the 500 to 15,000 mg/l range, although more concentrated wastes can be treated if they are first diluted with water. Below 500 mg/l, the rates of wet oxidation of most organic constituents are too slow for efficient application of this technology. For these low-concentration wastes, those technologies applicable to treatment of more dilute waste streams, such as biological treatment or carbon adsorption, may be selected instead of wet air oxidation.

Second, wet air oxidation can be applied to wastes that have significant concentrations of metals (roughly 2 percent), whereas carbon adsorption, biological treatment, and other forms of chemical oxidation may experience difficulties in treating such wastes.

It is important to point out that wet air oxidation proceeds by a series of reaction steps and the intermediate products formed are not always as readily oxidized as are the original constituents; therefore, the process does not always achieve complete oxidation of the organic constituents. Accordingly, in applying this technology it is important to assess potential products of incomplete oxidation to determine whether further treatment is necessary or whether this technology is appropriate at all.

Studies of the wet air oxidation of different compounds have led to the following empirical observations concerning a compound's susceptibility to wet air oxidation based on its chemical structure:

a. Aliphatic compounds, even with multiple halogen atoms, can be destroyed within conventional wet oxidation conditions. Oxygenated compounds (such as low molecular weight alcohols, aldehydes, ketones, and carboxylic acids) form, but these compounds are readily biotreatable.

b. Aromatic hydrocarbons, such as toluene, acenaphthene, or pyrene, are easily oxidized.

c. Halogenated aromatic compounds can be oxidized provided there is at least one nonhalogen functional group present on the ring (i.e., pentachlorophenol (-OH) or 2,4,6-trichloroaniline ($-NH_2$)).

d. Halogenated aromatic compounds, such as 1,2-dichlorobenzene, and PCBs, such as Aroclor 1254, are resistant to wet air oxidation under conventional conditions.

e. Halogenated ring compounds, such as the pesticides aldrin, dieldrin, and endrin, are expected to be resistant to conventional wet air oxidation.

f. DDT, although destroyed, results in the formation of intractable oils in conventional wet air oxidation.

g. In heterocyclic compounds containing oxygen, nitrogen, or sulfur, the O, N, or S atoms provide a point of attack for oxidation; thus these compounds are expected to be destroyed by wet air oxidation.

(2) Underlying Principles of Operation

The wet air oxidation of aqueous wastes is accomplished at high temperatures and pressures. The typical operating range of temperature for the treatment process is 175°3[illegible]°C. The pressure must be maintained at a level high enough to prevent excessive evaporation of the liquid phase at these temperatures, generally between 300 and 3000 psi. At these elevated temperatures and pressures, the solubility of oxygen in water is dramatically increased, thus providing a strong driving force for the oxidation. The reaction must take place in the aqueous phase because the chemical reactions involve both oxygen (oxidation) and water (hydrolysis). The wet air oxidation process for a specific organic compound generally involves a number of oxidation and hydrolysis reactions in series, which degrade the initial compound by steps into a series of compounds of simpler structure ending with carbon dioxide, water, and other very simple organic compounds. Complete wet air oxidation results in the conversion of hazardous compounds completely into carbon dioxide, water vapor, ammonia (in the case of nitrogen-containing wastes), sulfate (in the case of sulfur-containing wastes), and halogen acids (in the case of halogenated wastes).

The amount of information available is not sufficient to unequivocally determine the reaction mechanism or the reaction rates for individual process steps. However, it is reasonable to assume that at least trace quantities of partial degradation products will remain in the treated wastewaters. For this reason, effluents from wet air oxidation processes may be given subsequent treatment, such as chemical oxidation, biological treatment, or carbon absorption, before being discharged.

(3) Description of Wet Air Oxidation Process

A conventional wet air oxidation system consists of a high-pressure liquid feed pump, an oxygen source (air compressor or liquid oxygen vaporizer), a reactor, heat exchangers, a vapor-liquid separator, and process regulators. A basic flow diagram is shown in Figure 3-1.

Generally, batch wet air oxidation operates as follows. First, a copper catalyst solution may be mixed with the aqueous waste stream if preliminary testing indicates that a catalyst is necessary. The waste is then pumped into the reaction chamber. The aqueous waste is pressurized and heated to a prespecified temperature. After reaction conditions have been established, air is fed to the reactor for the duration of the Figure design reaction time. At the completion of the wet air oxidation process, suspended solids or gases are removed and the remaining treated aqueous waste is either discharged directly or fed to a secondary treatment system, such as a biological treatment unit, if further processing is necessary prior to discharge.

Wet air oxidation can also be operated as a continuous process. In continuous operation, the hot reactor effluent is used to preheat the influent waste stream. The waste is then pressurized, mixed with air, and fed to the reactor. Waste feed flow rate controls the reactor residence time.

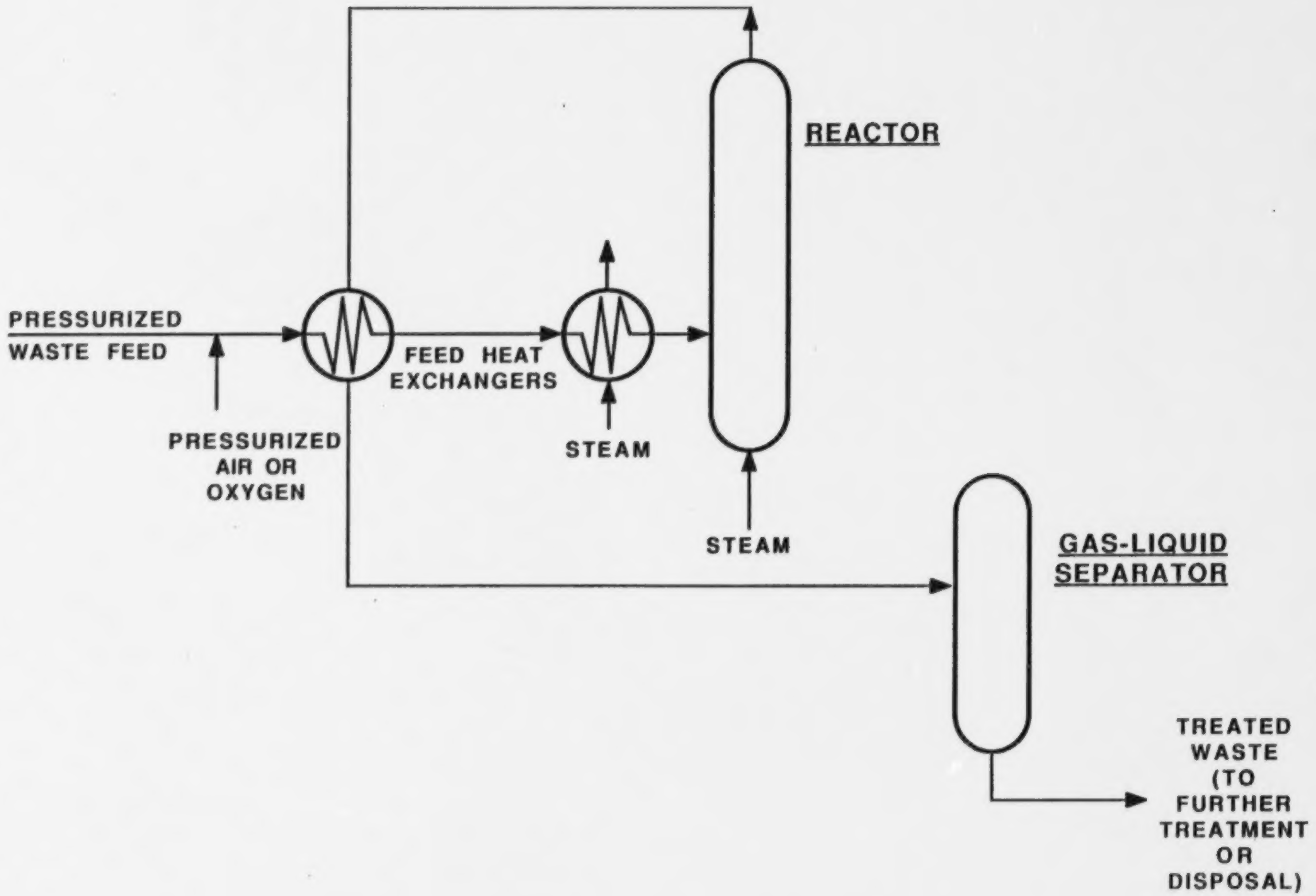

PRESSURIZED
WASTE FEED
PRESSURIZED
AIR OR
OXYGEN
FEED HEAT
EXCHANGERS
STEAM
REACTOR
STEAM
GAS-LIQUID
SEPARATOR
TREATED
WASTE
(TO
FURTHER
TREATMENT
OR
DISPOSAL)

FIGURE 1 WET AIR OXIDATION PROCESS FLOW DIAGRAM.

(4) Waste Characteristics Affecting Performance (WCAPs)

In determining whether performance standards can be transferred to an untested waste from a previously tested waste, EPA will examine the following waste characteristics: (a) chemical oxygen demand and (b) the presence of interfering substances.

(a) Chemical oxygen demand. The chemical oxygen demand (COD) of the waste is a measure of the oxygen required for complete oxidation of the oxidizable waste constituents. There is a physical limit to the amount of oxygen that can be supplied to the waste that is based on the solubility of oxygen and the rate of dissolution of oxygen from the gas phase to the liquid phase. This sets an upper limit on the amount of oxidizable compounds that can be treated by wet air oxidation. Thus, high-COD wastes may require dilution for effective treatment to occur.

(b) Presence of interfering substances. In some cases, addition of a water-soluble copper salt catalyst to the waste before processing is necessary for efficient oxidation treatment (for example, for oxidation of some halogenated organics). Other metals have been tested and have been found to be less effective. Interfering substances for the wet air oxidation process are essentially those that cause the formation of insoluble copper salts when copper catalysts are being used. To be effective, the copper ions must be dissolved in solution. Sulfide, carbonate, and other negative ions that form insoluble copper salts may interfere with treatment effectiveness if present in significant amounts in wastes for which catalysts are necessary for effective treatment. If an untested waste for which a catalyst is necessary has a signficantly higher concentration of sulfide, carbonate, or other anion that forms an insoluble salt than the tested waste, then treatment performance may not be transferable to that waste.

(5) Design and Operating Parameters

EPA's analysis of whether a wet air oxidation treatment unit is well designed and well operated will focus on the following parameters: (a) temperature, (b) residence time, (c) excess oxygen concentration, (d) pressure, and (e) addition of catalyst.

(a) Temperature. Temperature is the most important parameter affecting the system. The design temperature must be high enough to allow the oxidation reactions to proceed at acceptable rates. Raising the temperature increases the wet air oxidation rate by enhancing oxygen solubility and oxygen diffusivity. The process is normally operated in the temperature range of 175-325°C, depending on the hazardous constituent(s) to be treated. EPA will monitor the reactor temperature during oxidation to ensure that the design temperature is maintained.

(b) Residence time. Residence time is important in ensuring that the wastes are in the reactor long enough for the oxidation reaction to reach completion. In a continuous system, the size of the reactor and the waste flow rate determine residence time. Typically, the reaction rates are relatively fast for the first 30 minutes; after 60 minutes, the rates become slow. Typical residence times, therefore, are approximately 1 hour or slightly longer. EPA will monitor the reaction time for batch processes and the waste feed flow rate for continuous processes.

(c) Excess oxygen concentration. The system must be designed to supply adequate amounts of oxygen for the compounds to be oxidized. An estimate of the amount of oxygen needed can be made based on the COD content of the untreated waste; excess oxygen should be supplied to ensure complete oxidation. The source of oxygen is compressed air or a high-pressure pure oxygen stream. The excess oxygen concentration (the concentration of oxygen in the gas leaving the reactor) can be continuously monitored by sampling of the vent gas to ensure that an adequate amount of oxygen or air is being supplied.

(d) Pressure. The design pressure must be high enough to prevent excessive evaporation of water at the specified reactor temperature; this condition allows the oxidation reaction to occur in the aqueous phase, thereby improving treatment effectiveness. Continuous pressure monitoring and recording help ensure that the treatment system is operating at design conditions. As with temperature, the Agency will monitor the pressure during a treatment test to ensure that proper design conditions are maintained during treatment.

(e) Addition of catalyst. Adding a catalyst that promotes oxygen transfer and thus enhances oxidation has the effect of lowering the necessary reactor temperature and/or improving the level of destruction of oxidizable compounds. For waste constituents that are more difficult to oxidize, catalyst addition may be necessary to effectively destroy the constituent of concern. Catalysts typically used for this purpose include copper bromide and copper nitrate. If a catalyst is required, EPA will monitor the type, quantity, and method of addition of the catalyst.

3.3.4 Incineration

This section addresses the commonly used incineration technologies: liquid injection, rotary kiln, fluidized bed, and fixed hearth. A discussion is provided regarding the applicability of these technologies, the underlying principles of operation, a technology description, waste characteristics that affect performance, and, finally, important design and operating parameters. As appropriate, the subsections are divided by type of incineration unit.

(1) Applicability and use of incineration.

(a) Liquid injection. Liquid injection is applicable to wastes that have viscosity values low enough that the waste can be atomized in the combustion chamber. A range of literature maximum viscosity values are reported, with the low being 100 SSU and the high being 10,000 SSU. It is important to note that viscosity is temperature dependent so that while liquid injection may not be applicable to a waste at ambient conditions, it may be applicable when the waste is heated. Other factors that affect the use of liquid injection are particle size and the presence of suspended solids. Both of these waste parameters can cause plugging of the burner nozzle.

(b) Rotary kiln/fluidized bed/fixed hearth. These incineration technologies are applicable to a wide range of hazardous wastes. They can be used on wastes that contain high or low total organic content, high or low filterable solids, various viscosity ranges, and a range of other waste parameters. EPA has not found these technologies to be demonstrated on wastes that are composed essentially of metals with low organic concentrations. In addition, the Agency expects that air emissions from incinerating some of the high metal content wastes may not be compatible with existing and future air emission limits without emission controls far more extensive than those currently used.

(2) Underlying principles of operation.

(a) Liquid injection. The basic operating principle of this incineration technology is that incoming liquid wastes are volatilized and then additional heat is supplied to the waste to destabilize the chemical bonds. Once the chemical bonds are broken, these constituents react with oxygen to form carbon dioxide and water vapor. The energy needed to destabilize the bonds is referred to as the energy of activation.

(b) Rotary kiln and fixed hearth. There are two distinct principles of operation for these incineration technologies, one for each of the chambers involved. In the primary chamber, energy, in the form of heat, is transferred to the waste to achieve volatilization of the various organic waste constituents. During this volatilization process some of the organic constituents will oxidize to carbon dioxide and water vapor. In the secondary chamber, additional heat is supplied to overcome the energy requirements needed to destabilize the chemical bonds and allow the constituents to react with excess oxygen to form carbon dioxide and water vapor. The principle of operation for the secondary chamber is similar to that of liquid injection.

(c) Fluidized bed. The principle of operation for this incineration technology is somewhat different from that for rotary kiln and fixed hearth incineration relative to the functions of the primary and secondary chambers. In fluidized bed incineration, the purpose of the primary chamber is not only to volatilize the wastes but also to essentially combust the waste. Destruction of the waste organics can be accomplished to a better degree in the primary chamber of a fluidized bed incinerator than in that of a rotary kiln or fixed hearth incinerator because of (1) improved heat transfer from fluidization of the waste using forced air and (2) the fact that the fluidization process provides sufficient oxygen and turbulence to convert the organics to carbon dioxide and water vapor. The secondary chamber (referred to as the freeboard) generally does not have an afterburner; however, additional time is provided for conversion of the organic constituents to carbon dioxide, water vapor, and hydrochloric acid if chlorine is present in the waste.

(3) Description of the incineration process.

(a) Liquid injection. The liquid injection system is capable of incinerating a wide range of gases and liquids. The combustion system has a simple design with virtually no moving parts. A burner or nozzle atomizes the liquid waste and injects it into the combustion chamber, where it burns in the presence of air or oxygen. A forced draft system supplies the combustion chamber with air to provide oxygen for combustion and turbulence for mixing. The combustion chamber is usually a cylinder lined with refractory (i.e., heat-resistant) brick and can be fired horizontally, vertically upward, or vertically downward. Figure 3-2 illustrates a liquid injection incineration system.

(b) Rotary kiln. A rotary kiln is a slowly rotating, refractory-lined cylinder that is mounted at a slight incline from the horizontal (see Figure 3-3). Solid wastes enter at the high end of the kiln, and liquid or gaseous wastes enter through atomizing nozzles in the kiln or afterburner section. Rotation of the kiln exposes the solids to the heat, vaporizes them, and allows them to combust by mixing with air. The rotation also causes the ash to move to the lower end of the kiln, where it can be removed. Rotary kiln systems usually have a secondary combustion chamber or afterburner following the kiln for further combustion of the volatilized components of solid wastes.

(c) Fluidized bed. A fluidized bed incinerator consists of a column containing inert particles such as sand, which is referred to as the bed. Air, driven by a blower, enters the bottom of the bed to fluidize the sand. Air passage through the bed promotes rapid and uniform mixing of the injected waste material within the fluidized bed. The fluidized bed has an extremely high heat capacity (approximately three times that of flue gas at the same temperature), thereby providing a large heat reservoir. The injected waste reaches ignition temperature

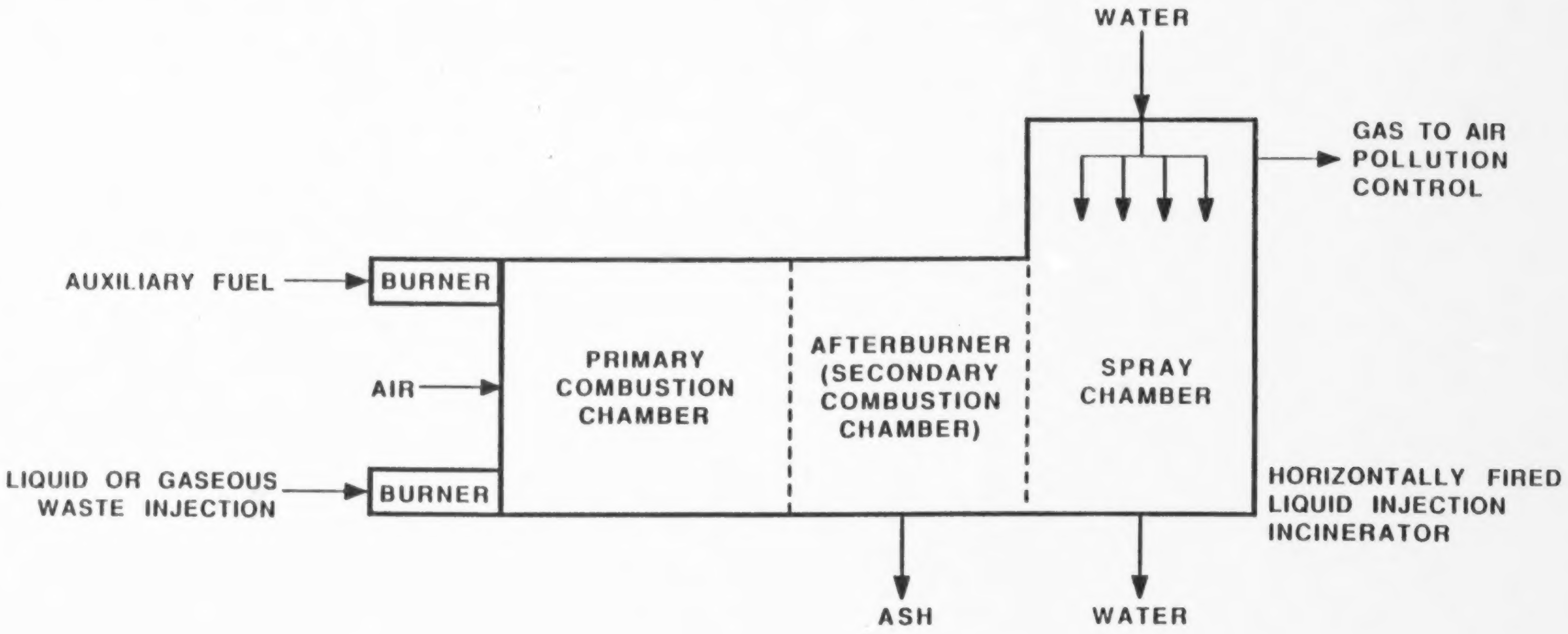

WATER
GAS TO AIR POLLUTION CONTROL
AUXILIARY FUEL
BURNER
AIR
LIQUID OR GASEOUS WASTE INJECTION
BURNER
PRIMARY COMBUSTION CHAMBER
AFTERBURNER (SECONDARY COMBUSTION CHAMBER)
SPRAY CHAMBER
HORIZONTALLY FIRED LIQUID INJECTION INCINERATOR
ASH
WATER

FIGURE
LIQUID INJECTION INCINERATOR

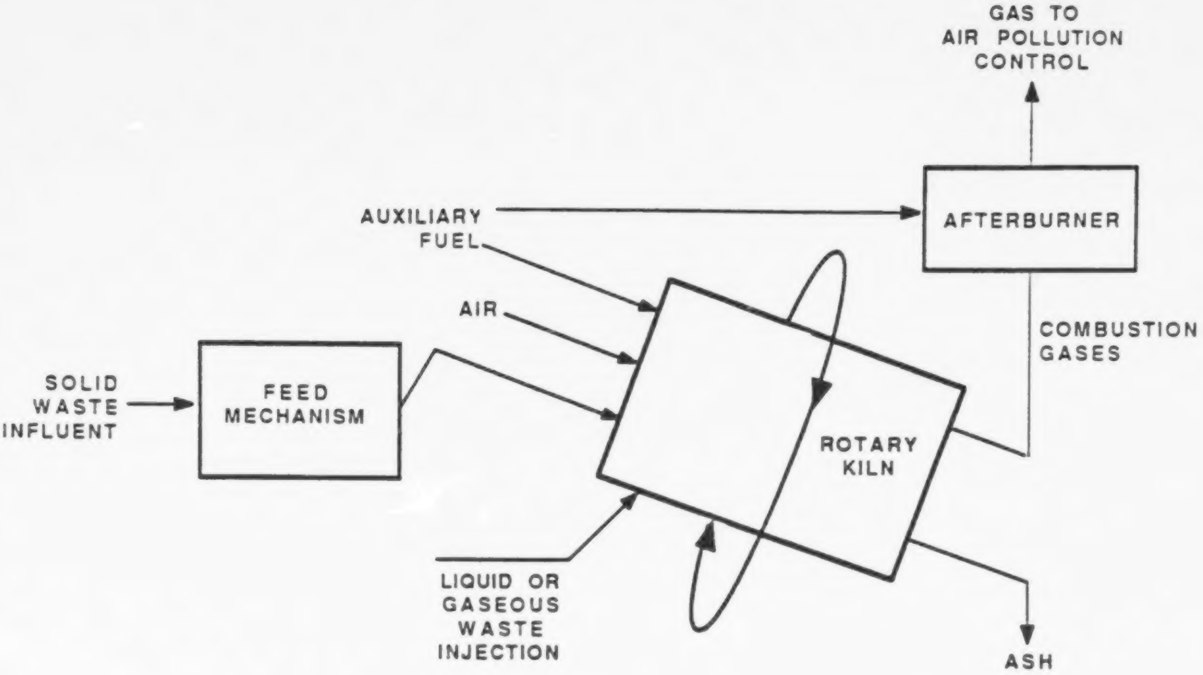

GAS TO
AIR POLLUTION
CONTROL
AFTERBURNER
AUXILIARY
FUEL
AIR
COMBUSTION
GASES
SOLID
WASTE
INFLUENT
FEED
MECHANISM
ROTARY
KILN
LIQUID OR
GASEOUS
WASTE
INJECTION
ASH

FIGURE
ROTARY KILN INCINERATOR

quickly and transfers the heat of combustion back to the bed. Continued bed agitation by the fluidizing air allows larger particles to remain suspended in the combustion zone (see Figure 3-4).

(d) Fixed hearth. Fixed hearth incineration, also called controlled air or starved air incineration, is another major technology used for hazardous waste incineration. Fixed hearth incineration is a two-stage combustion process (see Figure 3-5). Waste is ram-fed into the first stage, or primary chamber, and burned at less than stoichiometric conditions. The resultant smoke and pyrolysis products, consisting primarily of volatile hydrocarbons and carbon monoxide, along with the normal products of combustion, pass to the secondary chamber. Here, additional air is injected to complete the combustion. This two-stage process generally yields low stack particulate and carbon monoxide (CO) emissions. The primary chamber combustion reactions and combustion gas are maintained at low levels by the starved air conditions so that particulate entrainment and carryover are minimized.

(e) Air pollution controls. Following incineration of hazardous wastes, combustion gases are generally further treated in an air pollution control system. The presence of chlorine or other halogens in the waste requires a scrubbing or absorption step to remove hydrochloric acid and other halo-acids from the combustion gases. Ash in the waste is not destroyed in the combustion process. Depending on its composition, ash will exit either as bottom ash, at the discharge end of a kiln or hearth for example, or as particulate matter (fly ash) suspended in the combustion gas stream. Particulate emissions from most

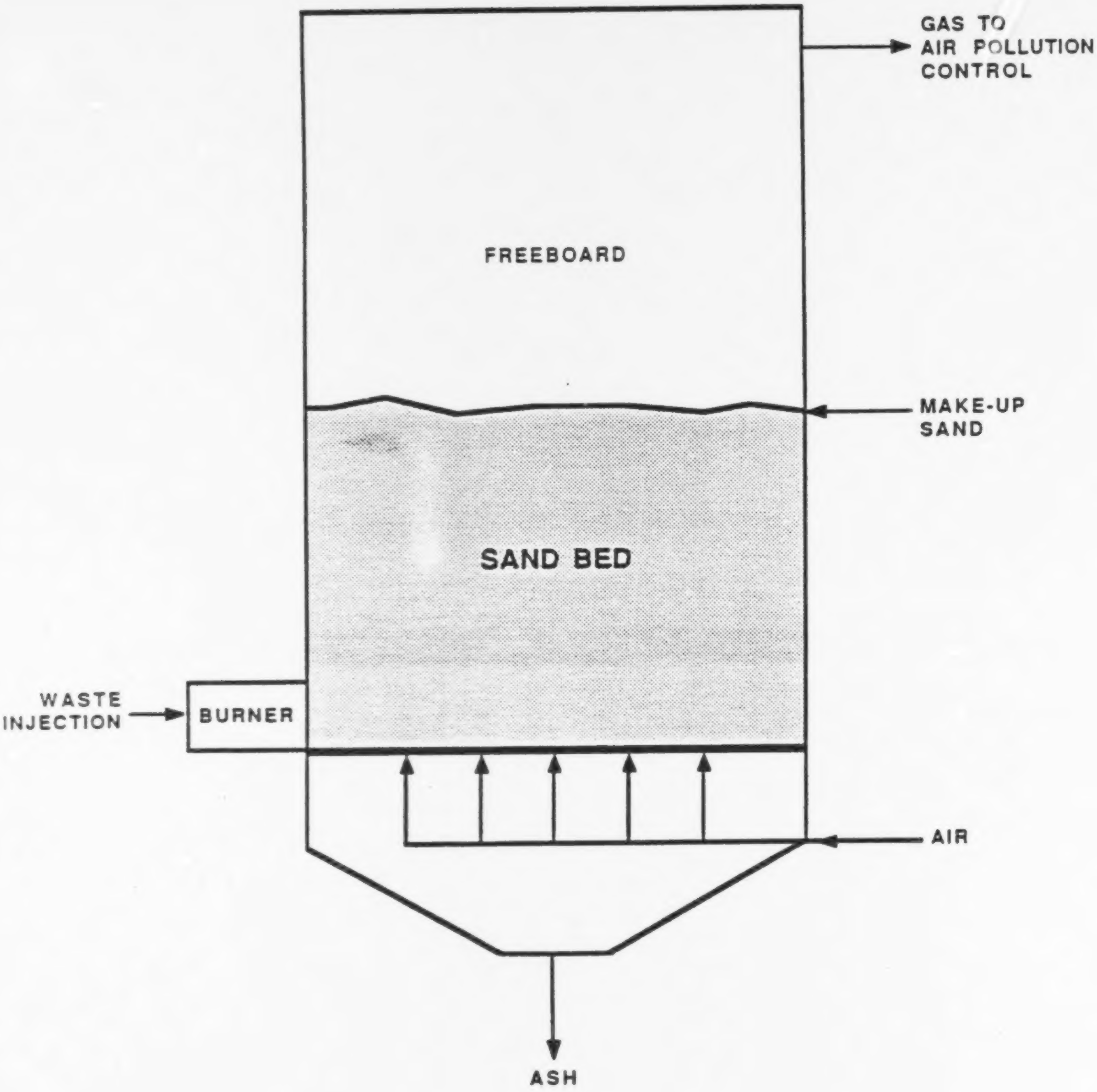

GAS TO
AIR POLLUTION
CONTROL
FREEBOARD
MAKE-UP
SAND
SAND BED
WASTE
INJECTION
BURNER
AIR
ASH

FIGURE
FLUIDIZED BED INCINERATOR

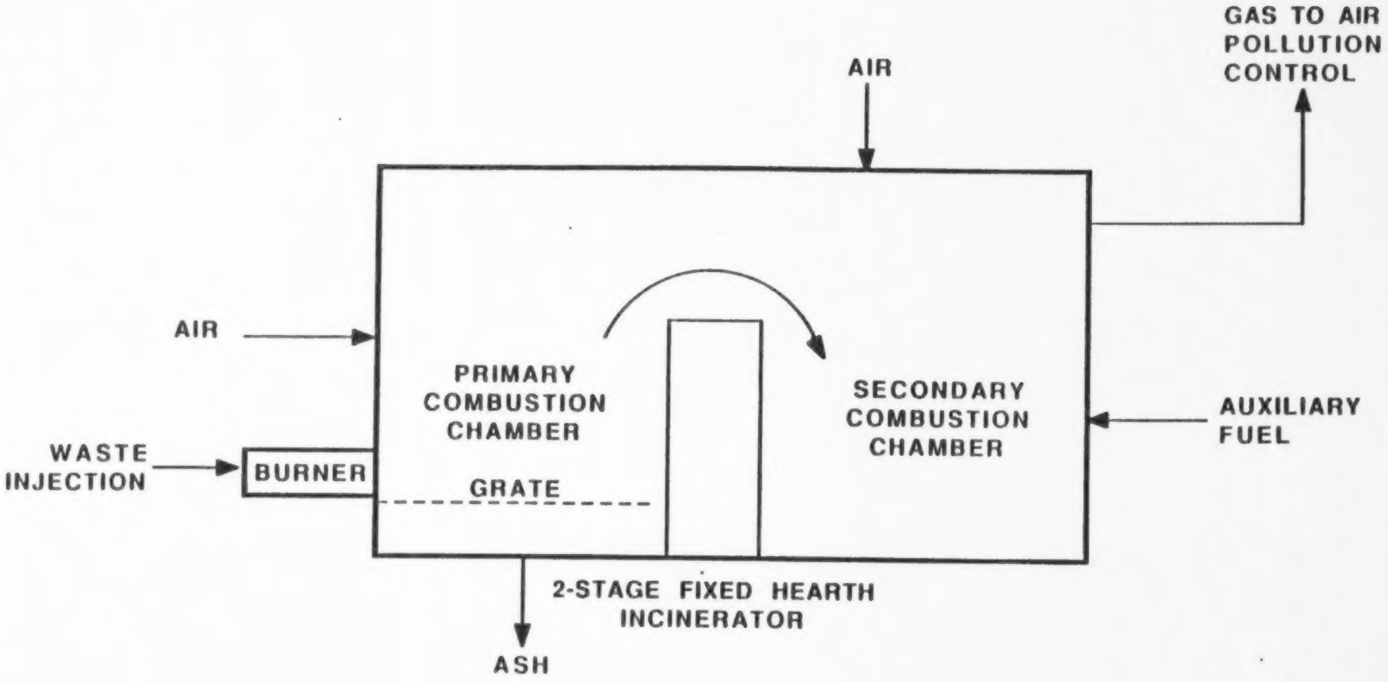

GAS TO AIR POLLUTION CONTROL
AIR
AIR
PRIMARY COMBUSTION CHAMBER
SECONDARY COMBUSTION CHAMBER
AUXILIARY FUEL
WASTE INJECTION
BURNER
GRATE
2-STAGE FIXED HEARTH INCINERATOR
ASH

FIGURE
FIXED HEARTH INCINERATOR

hazardous waste combustion systems generally have particle diameters of less than 1 micron and require high-efficiency collection devices to minimize air emissions. In addition, scrubber systems provide an additional buffer against accidental releases of incompletely destroyed waste products, which result from poor combustion efficiency or combustion upsets, such as flameouts.

(4) Waste characteristics affecting performance.

(a) Liquid injection. In determining whether liquid injection is likely to achieve the same level of performance on an untested waste as on a previously tested waste, the Agency will compare dissociation bond energies of the constituents in the untested and tested wastes. This parameter is being used as a surrogate indicator of activation energy which, as discussed previously, destabilizes molecular bonds. In theory, the bond dissociation energy would be equal to the activation energy; in practice, however, this is not always the case. Other energy effects (e.g., vibrational effects, the formation of intermediates, and interactions between different molecular bonds) may have a significant influence on activation energy.

Because of the shortcomings of bond energies in estimating activation energy, EPA analyzed other waste characteristic parameters to determine whether these parameters would provide a better basis for transferring treatment standards from an untested waste to a tested waste. These parameters include heat of combustion, heat of formation, use of available kinetic data to predict activation energies, and general structural class. All of these parameters were rejected for the reasons provided below.

The heat of combustion measures only the difference in energy of the products and reactants; it does not provide information on the transition state. Heat of formation is used as a tool to predict whether reactions are likely to proceed; however, there are a significant number of hazardous constituents for which these data are not available. Use of kinetic data was rejected because these data are limited and could not be used to calculate free energy values (ΔG) for the wide range of hazardous constituents to be addressed by this rule. Finally, EPA decided not to use structural classes because the Agency believes that evaluation of bond dissociation energies allows for a more direct determination of whether a constituent will be destabilized.

(b) Rotary kiln/fluidized bed/fixed hearth. Unlike liquid injection, these incineration technologies also generate a residual ash. Accordingly, in determining whether these technologies are likely to achieve the same level of performance on an untested waste as on a previously tested waste, EPA would need to examine the waste characteristics that affect volatilization of organics from the waste, as well as destruction of the organics once volatilized. Relative to volatilization, EPA will examine thermal conductivity of the entire waste and boiling point of the various constituents. As with liquid injection, EPA will examine bond energies in determining whether treatment standards for scrubber water residuals can be transferred from a tested waste to an untested waste. Below is a discussion of how EPA arrived at thermal conductivity and boiling point as the best method to assess volatilization of organics from the waste; the discussion relative to bond energies is the same for these technologies as for liquid injection and will not be repeated here.

(i) Thermal conductivity. Consistent with the underlying principles of incineration, a major factor with regard to whether a particular constituent will volatilize is the transfer of heat through the waste. In the case of rotary kiln, fluidized bed, and fixed hearth incineration, heat is transferred through the waste by three mechanisms: radiation, convection, and conduction. For a given incinerator, heat transferred through various wastes by radiation is more a function of the design and type of incinerator than of the waste being treated. Accordingly, the type of waste treated will have a minimal impact on the amount of heat transferred by radiation. With regard to convection, EPA also believes that the type of heat transfer will generally be more a function of the type and design of the incinerator than of the waste itself. However, EPA is examining particle size as a waste characteristic that may significantly impact the amount of heat transferred to a waste by convection and thus impact volatilization of the various organic compounds. The final type of heat transfer, conduction, is the one that EPA believes will have the greatest impact on volatilization of organic constituents. To measure this characteristic, EPA will use thermal conductivity; an explanation of this parameter, as well as how it can be measured, is provided below.

Heat flow by conduction is proportional to the temperature gradient across the material. The proportionality constant is a property of the material and is referred to as the thermal conductivity. (Note: The analytical method that EPA has identified for measurement of thermal conductivity is named "Guarded, Comparative, Longitudinal Heat Flow Technique"; it is described in Appendix E.) In theory, thermal conductivity would always provide a good indication of whether a constituent in an untested waste would be treated to the same extent in the primary incinerator chamber as the same constituent in a previously tested waste.

In practice, thermal conductivity has some limitations in assessing the transferability of treatment standards; however, EPA has not identified a parameter that can provide a better indication of the heat transfer characteristics of a waste. Below is a discussion of both the limitations associated with thermal conductivity and the other parameters considered.

Thermal conductivity measurements, as part of a treatability comparison for two different wastes through a single incinerator, are most meaningful when applied to wastes that are homogeneous (i.e., major constituents are essentially the same). As wastes exhibit greater degrees of nonhomogeneity (e.g., significant concentration of metals in soil), then thermal conductivity becomes less accurate in predicting treatability because the measurement essentially reflects heat flow through regions having the greatest conductivity (i.e., the path of least resistance) and not heat flow through all parts of the waste.

Btu value, specific heat, and ash content were also considered for predicting heat transfer characteristics. These parameters can no better account for nonhomogeneity than can thermal conductivity; additionally, they are not directly related to heat transfer characteristics. Therefore, these parameters do not provide a better indication of the heat transfer that will occur in any specific waste.

(ii) Boiling point. Once heat is transferred to a constituent within a waste, removal of this constituent from the waste will depend on its volatility. EPA is using boiling point as a surrogate of volatility of the constituent. Compounds with lower boiling points have higher vapor pressures and therefore would be more likely to vaporize. The Agency recognizes that this parameter does not take into consideration the impact of other compounds in the waste on the boiling point of a constituent in a mixture; however, the Agency is not aware of a better measure of volatility that can easily be determined.

(5) Design and operating parameters.

(a) Liquid injection. For a liquid injection unit, EPA's analysis of whether the unit is well designed will focus on (1) the likelihood that sufficient energy is provided to the waste to overcome the activation level for breaking molecular bonds and (2) whether sufficient oxygen is present to convert the waste constituents to carbon dioxide and water vapor. The specific design parameters that the Agency will evaluate to assess whether these conditions are met are temperature, excess oxygen, and residence time. Below is a discussion of why EPA believes these parameters to be important, as well as a discussion of how these parameters will be monitored during operation.

It is important to point out that, relative to the development of land disposal restriction standards, EPA is concerned with these design parameters only when a quench water or scrubber water residual is generated from treatment of a particular waste. If treatment of a particular waste in a liquid injection unit would not generate a wastewater stream, then the Agency, for purposes of land disposal treatment standards, would be concerned only with the waste characteristics that affect selection of the unit, not with the above-mentioned design parameters.

(i) Temperature. Temperature is important in that it provides an indirect measure of the energy available (i.e., Btu/hr) to overcome the activation energy of waste constituents. As the design temperature increases, it is more likely that the molecular bonds will be destabilized and the reaction completed.

The temperature is normally controlled automatically through the use of instrumentation that senses the temperature and automatically adjusts the amount of fuel and/or waste being fed. The temperature signal transmitted to the controller can be simultaneously transmitted to a recording device, referred to as a strip chart, and thereby continuously recorded. To fully assess the operation of the unit, it is important to know not only the exact location in the incinerator at which the temperature is being monitored but also the location of the design temperature.

(ii) Excess oxygen. It is important that the incinerator contain oxygen in excess of the stoichiometric amount necessary to convert the organic compounds to carbon dioxide and water vapor. If insufficient oxygen is present, then destabilized waste constituents could recombine to the same or other BDAT list organic compounds and potentially cause the scrubber water to contain higher concentrations of BDAT list constituents than would be the case for a well-operated unit.

In practice, the amount of oxygen fed to the incinerator is controlled by continuous sampling and analysis of the stack gas. If the amount of oxygen drops below the design value, then the analyzer transmits a signal to the valve controlling the air supply and thereby increases the flow of oxygen to the afterburner. The analyzer simultaneously transmits a signal to a recording device so that the amount of excess oxygen can be continuously recorded. Again, as with temperature, it is important to know the location at which the combustion gas is being sampled.

(iii) Carbon monoxide. Carbon monoxide is an important operating parameter because it provides an indication of the extent to which the waste organic constituents are being converted to carbon dioxide and water vapor. An increase in the carbon monoxide level indicates that greater amounts of organic waste constituents are unreacted or partially reacted. Increased carbon monoxide levels can result from insufficient excess oxygen, insufficient turbulence in the combustion zone, or insufficient residence time.

(iv) Waste feed rate. The waste feed rate is important to monitor because it is correlated to the residence time. The residence time is associated with a specific Btu energy value of the feed and a specific volume of combustion gas generated. Prior to incineration, the Btu value of the waste is determined through the use of a laboratory device known as a bomb calorimeter. The volume of combustion gas generated from the waste to be incinerated is determined from an analysis referred to as an ultimate analysis. This analysis determines the amount of elemental constituents present, which include carbon, hydrogen, sulfur, oxygen, nitrogen, and halogens. Using this analysis plus the total amount of air added, one can calculate the volume of combustion gas. After both the Btu content and the expected combustion gas volume have been determined, the feed rate can be fixed at the desired residence time. Continuous monitoring of the feed rate will determine whether the unit is being operated at a rate corresponding to the designed residence time.

(b) Rotary kiln. For this incineration, EPA will examine both the primary and secondary chamber in evaluating the design of a particular incinerator. Relative to the primary chamber, EPA's assessment of design will focus on whether sufficient energy is likely to be provided to the waste to volatilize the waste constituents. For the secondary chamber, analogous to the sole liquid injection incineration chamber, EPA will examine the same parameters discussed previously under liquid injection incineration. These parameters will not be discussed again here.

The particular design parameters to be evaluated for the primary chamber are kiln temperature, residence time, and revolutions per minute. Below is a discussion of why EPA believes these parameters to be important, as well as a discussion of how these parameters will be monitored during operation.

(i) Temperature. The primary chamber temperature is important, in that it provides an indirect measure of the energy input (i.e., Btu/hr) available for heating the waste. The higher the temperature is designed to be in a given kiln, the more likely it is that the constituents will volatilize. As discussed earlier under "Liquid injection," temperature should be continuously monitored and recorded. Additionally, it is important to know the location of the temperature sensing device in the kiln.

(ii) Residence time. This parameter is important in that it affects whether sufficient heat is transferred to a particular constituent in order for volatilization to occur. As the time that the waste is in the kiln is increased, a greater quantity of heat is transferred to the hazardous waste constituents. The residence time will be a function of the specific configuration of the rotary kiln, including the length and diameter of the kiln, the waste feed rate, and the rate of rotation.

(iii) Revolutions per minute (RPM). This parameter provides an indication of the turbulence that occurs in the primary chamber of a rotary kiln. As the turbulence increases, the quantity of heat transferred to the waste would also be expected to increase. However, as the RPM value increases, the residence time decreases, resulting in a reduction of the quantity of heat transferred to the waste. This parameter needs to be carefully evaluated because it provides a balance between turbulence and residence time.

(c) Fluidized bed. As discussed previously in the section "Underlying principles of operation," the primary chamber accounts for almost all of the conversion of organic wastes to carbon dioxide, water vapor, and acid gas (if halogens are present). The secondary chamber will generally provide additional residence time for thermal oxidation of the waste constituents. Relative to the primary chamber, the parameters that the Agency will examine in assessing the effectiveness of the design are temperature, residence time, and bed pressure differential. The first two were included in the discussion of the rotary kiln and will not be discussed here. The last, bed pressure differential, is important in that it provides an indication of the amount of turbulence and therefore indirectly the amount of heat supplied to the waste. In general, as the pressure drop increases, both the turbulence and heat supplied increase. The pressure drop through the bed should be continuously monitored and recorded to ensure that the designed value is achieved.

(d) Fixed hearth. The design considerations for this incineration unit are similar to those for a rotary kiln with the exception that rate of rotation (i.e., RPM) is not an applicable design parameter. For the primary chamber of this unit, the parameters that the Agency will examine in assessing how well the unit is designed are the same as those discussed under "Rotary kiln"; for the secondary chamber (i.e., afterburner), the design and operating parameters of concern are the same as those previously discussed under "Liquid injection."

3.4 Descriptions of BDAT List Metals Treatment Technologies

3.4.1 Hexavalent Chromium Reduction

(1) Applicability

The process of hexavalent chromium (Cr^{+6}) reduction involves conversion from the hexavalent form of chromium to the trivalent form (Cr^{+3}). This technology has wide application to hexavalent chromium wastes, including plating solutions, stainless steel acid baths and rinses, "chrome conversion" coating process rinses, and chromium pigment manufacturing wastes. Because this technology requires the pH to be in the acidic range, it would not be applicable to a waste that contains significant amounts of cyanide or sulfide. In such cases, lowering of the pH can result in the release of toxic gases such as hydrogen cyanide or hydrogen sulfide. It is important to note that additional treatment is required to remove trivalent chromium from the solution following reduction of the hexavalent chromium.

(2) Underlying Principles of Operation

The basic principle of treatment is to reduce the valence of chromium in solution (in the form of chromate or dichromate ions) from the hexavalent state to the trivalent state. "Reducing agents" used to affect the reduction include sodium sulfite ($Na_2S_2O_3$), sodium bisulfite ($NaHSO_3$), sodium metabisulfite ($Na_2S_2O_5$), sulfur dioxide (SO_2), sodium hydrosulfide (NaHS), or the ferrous form of iron (Fe^{+2}).

A typical reduction reaction, using sodium sulfite as the reducing agent, is as follows:

$$H_2(Cr^{+6})_2O_7 + 3Na_2SO_3 + 3H_2SO_4 \rightarrow (Cr^{+3})_2(SO_4)_3 + 3Na_2SO_4 + 4H_2O$$

The reaction is usually accomplished at pH values from 2 to 3.

At the completion of the chromium reduction step, the trivalent chromium compounds are precipitated from solution by raising the pH above 8. The insoluble trivalent chromium (in the form of chromium hydroxide) is then allowed to settle from solution. The precipitation reaction is as follows:

$$Cr_2(SO_4)_3 + 3Ca(OH)_2 \rightarrow 2Cr(OH)_3 + 3CaSO_4$$

(3) Physical Description of Chromium Reduction Process

The chromium reduction treatment process can be operated in a batch or continuous mode. A batch system consists of a reaction tank, a mixer to homogenize the contents of the tank, a supply of reducing agent, and a source of acid and base for pH control.

A continuous chromium reduction treatment system, as shown in Figure 3-6, usually includes a holding tank upstream of the reaction tank for flow and concentration equalization. It also includes instrumentation to automatically control the amount of reducing agent

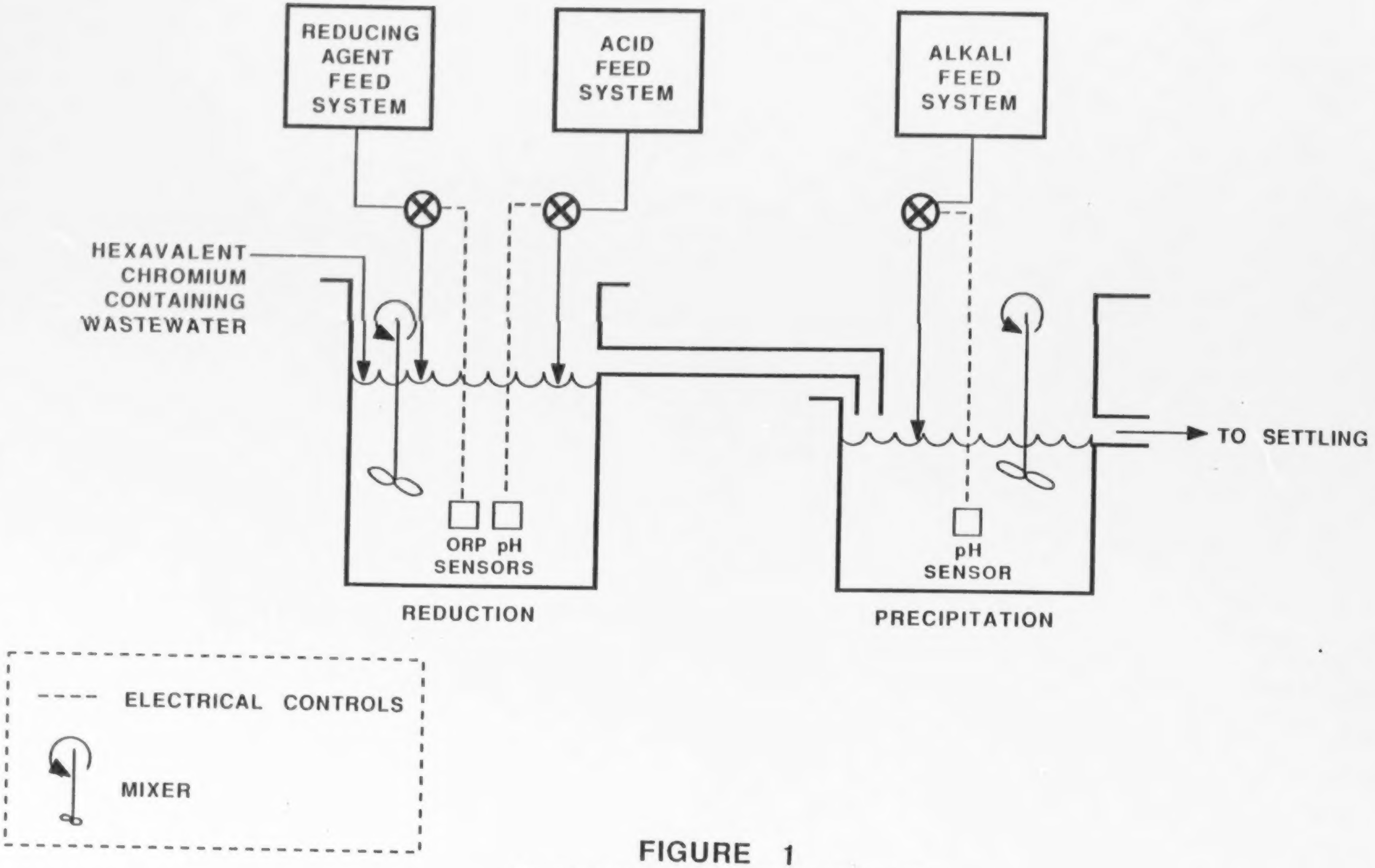

REDUCING AGENT FEED SYSTEM
ACID FEED SYSTEM
ALKALI FEED SYSTEM
HEXAVALENT CHROMIUM CONTAINING WASTEWATER
ORP pH SENSORS
REDUCTION
pH SENSOR
PRECIPITATION
TO SETTLING
ELECTRICAL CONTROLS
MIXER

FIGURE 1
CONTINUOUS HEXAVALENT
CHROMIUM REDUCTION SYSTEM

added and the pH of the reaction tank. The amount of reducing agent is controlled by the use of a sensor called an oxidation reduction potential (ORP) cell. The ORP sensor electronically measures, in millivolts, the level to which the redox reaction has proceeded at any given time. It must be noted, however, that the ORP reading is very pH dependent. Consequently, if the pH is not maintained at a steady value, the ORP will vary somewhat, regardless of the level of chromate reduction.

(4) Waste Characteristics Affecting Performance (WCAPs)

In determining whether performance standards can be transferred to an untested waste from a previously tested waste, EPA will examine the following waste characteristics: (a) concentration of oil and grease present in the waste and (b) concentration of other reducible metals.

(a) Concentration of oil and grease. EPA believes that these compounds could cause monitoring problems by fouling of instrumentation (e.g., electrodes for pH and ORP sensors). If the concentration of oil and grease in the untested waste is significantly higher than the concentration of oil and grease in the tested waste, then EPA will consider pretreating for oil and grease removal.

(b) Concentration of other reducible metals. Ionized metals (such as silver, copper, and mercury) can compete with chromium for reducing agents, thereby requiring greater amounts of reducing agents to completely reduce the chromium. If the concentration of reducible metals in the untested waste is significantly higher than that of the tested waste, then EPA will consider using higher amounts of reducing agents to achieve the desired reduction.

(5) Design and Operating Parameters. EPA will examine the following parameters in assessing the design and operation of a chromium reduction treatment system: (a) amount and type of reducing agent, (b) pH, (c) retention time, and (d) mixing.

(a) Amount and type of reducing agent. The choice of a reducing agent establishes the chemical reaction upon which the chromium reduction system is based. The amount of reducing agent must be monitored and controlled in both batch and continuous systems to ensure complete reduction. In batch systems, reducing agent is usually controlled by analysis of the hexavalent chromium remaining in solution, but it may also be controlled by using an ORP monitoring system. For continuous systems, the ORP reading is used to monitor and control the addition of reducing agent.

ORP will slowly change until the reduction reaction is completed at which point ORP will change rapidly. The set point for the ORP monitor is approximately the reading just after the rapid change has begun. The reduction system must then be monitored periodically to determine whether the selected set point needs further adjustment. EPA will monitor the hexavalent chromium remaining in solution for batch systems and the ORP for continuous systems to ensure that the hexavalent chromium is completely reduced.

(b) pH. For batch and continuous systems, pH is an important parameter because of its effect on the reduction reaction. The reaction speed is significantly reduced at pH values above approximately 4.0. For a batch system, the pH can be monitored intermittently during treatment. For a continuous system, the pH must be continuously monitored because of its effect on ORP. EPA will monitor the pH of the reduction system to ensure that the system is well operated.

(c) Retention time. Retention time should be adequate to ensure that the hexavalent chromium reduction reaction goes to completion. For batch systems, the retention time is controlled directly by adjusting the treatment time in the reaction tank. For continuous systems, the feed rate is controlled to ensure that the design retention time is achieved. EPA will monitor the retention time of the reduction system to ensure complete reduction.

(d) Mixing. The reduction system should be designed to provide adequate mixing in order to ensure uniform distribution of the reducing agent. There should be uniform concentration of chromium throughout the reactor. EPA will observe the reduction system to ensure that the system is providing adequate mixing.

3.4.2 Chemical Precipitation

(1) Applicability and use of chemical precipitation. Chemical precipitation is used when dissolved metals are to be removed from solution. This technology can be applied to a wide range of wastewaters containing dissolved BDAT list metals and other metals as well. This treatment process has been practiced widely by industrial facilities since the 1940s.

(2) Underlying principles of operation. The underlying principle of chemical precipitation is that metals in wastewater are removed by the addition of a treatment chemical that converts the dissolved metal to a metal precipitate. This precipitate is less soluble than the original metal compound and therefore settles out of solution, leaving a lower concentration of the metal present in the solution. The principal chemicals used to convert soluble metal compounds to the less soluble forms include lime ($Ca(OH)_2$), caustic (NaOH), sodium sulfide (Na_2S), and, to a lesser extent, soda ash (Na_2CO_3), phosphate, and ferrous sulfide (FeS).

The solubility of a particular compound will depend on the extent to which the electrostatic forces holding the ions of the compound together can be overcome. The solubility will change significantly with temperature; most metal compounds are more soluble as the temperature increases. Additionally, the solubility will be affected by the other constituents present in a waste. As a general rule, nitrates, chlorides, and sulfates are more soluble than hydroxides, sulfides, carbonates, and phosphates.

An important concept related to treatment of metals by hydroxide precipitation is pH. The pH of an aqueous solution provides a measure of the extent to which a solution contains an excess of either hydrogen or hydroxide ions. The pH scale ranges from 0 to 14, with 0 being the most acidic, 14 representing the highest alkalinity or hydroxide ion (OH^-) content, and 7 being neutral.

When hydroxide is used to precipitate the soluble metal compounds, the pH is frequently monitored to ensure that sufficient treatment chemicals are added. It is important to point out that pH is not a good measure of treatment chemical addition for compounds other than hydroxides; when sulfide is used, for example, facilities might use an oxidation-reduction potential meter (ORP) correlation to ensure that sufficient treatment chemical is used.

Following conversion of the relatively soluble metal compounds to metal precipitates, the effectiveness of chemical precipitation is a function of the physical removal, which usually relies on a settling process. A particle of a specific size, shape, and composition will settle at a specific velocity, as described by Stokes' Law. For a batch system, Stokes' Law is a good predictor of settling time because the pertinent particle parameters remain essentially constant. Nevertheless, in practice, settling time for a batch system is normally determined by empirical testing. For a continuous system, the theory of settling is complicated by factors such as turbulence, short-circuiting, and velocity gradients, increasing the importance of the empirical tests.

(3) Description of the technology. The equipment and instrumentation required for chemical precipitation vary depending on whether the system is batch or continuous. Both operations are discussed below; a schematic of the continuous system is shown in Figure 3-7.

For a batch system, chemical precipitation requires only a feed system for the treatment chemicals and a second tank where the waste can be treated and allowed to settle. When lime is used, it is usually added

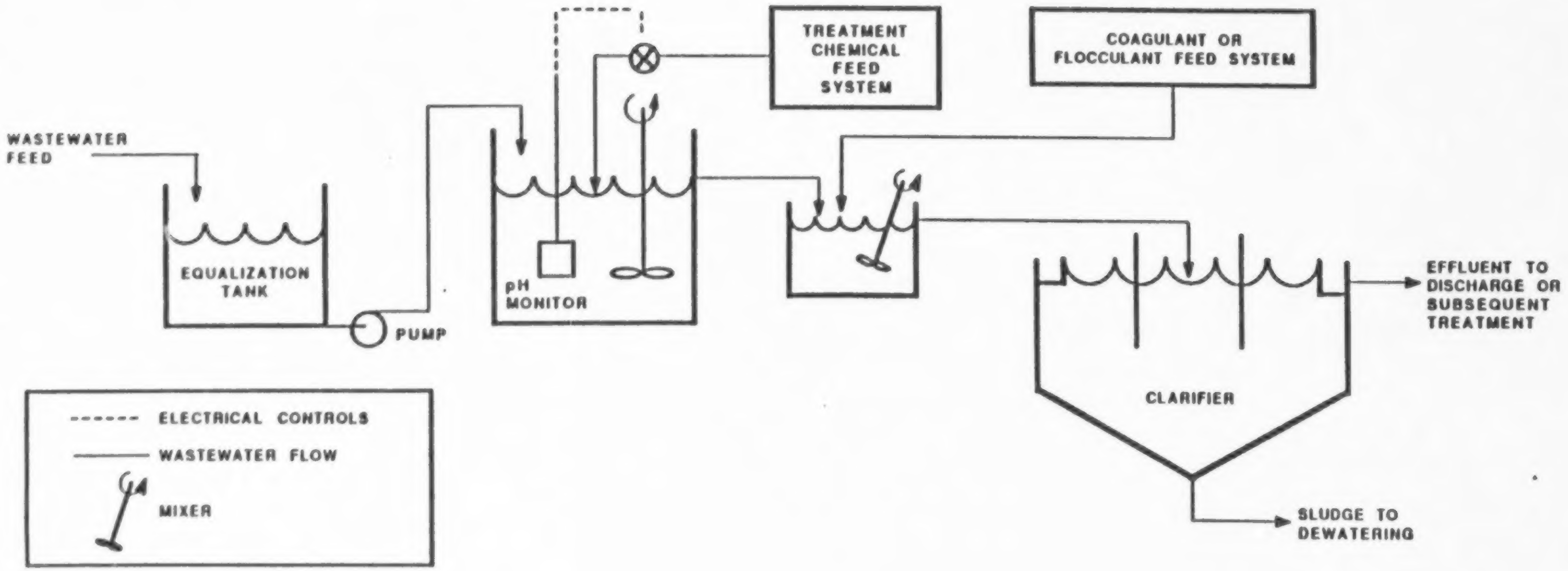

WASTEWATER FEED
EQUALIZATION TANK
PUMP
pH MONITOR
TREATMENT CHEMICAL FEED SYSTEM
COAGULANT OR FLOCCULANT FEED SYSTEM
CLARIFIER
EFFLUENT TO DISCHARGE OR SUBSEQUENT TREATMENT
SLUDGE TO DEWATERING
ELECTRICAL CONTROLS
WASTEWATER FLOW
MIXER

FIGURE CONTINUOUS CHEMICAL PRECIPITATION to the reaction tank in a slurry form. In a batch system, the supernate is usually analyzed before discharge, thus minimizing the need for instrumentation.

In a continuous system, additional tanks are necessary, as well as instrumentation to ensure that the system is operating properly. In this system, the first tank that the wastewater enters is referred to as an equalization tank. This is where the waste can be mixed in order to provide more uniformity, minimizing wide swings in the type and concentration of constituents being sent to the reaction tank. It is important to reduce the variability of the waste sent to the reaction tank because control systems inherently are limited with regard to the maximum fluctuations that can be managed.

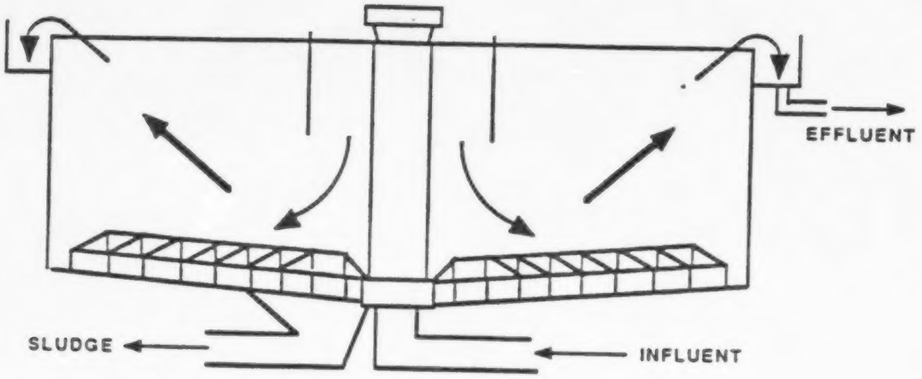
Following equalization, the waste is pumped to a reaction tank where treatment chemicals are added; the chemicals are added automatically by using instrumentation that senses the pH of the system and then pneumatically adjusts the position of the treatment chemical feed valve such that the design pH value is achieved. Both the complexity and the effectiveness of the automatic control system will vary depending on the variation in the waste and the pH range that is needed to properly treat the waste.

An important aspect of the reaction tank design is that it be well mixed so that the waste and the treatment chemicals are both dispersed throughout the tank, in order to ensure commingling of the reactant and the treatment chemicals. In addition, effective dispersion of the treatment chemicals throughout the tank is necessary to properly monitor and thereby control the amount of treatment chemicals added.

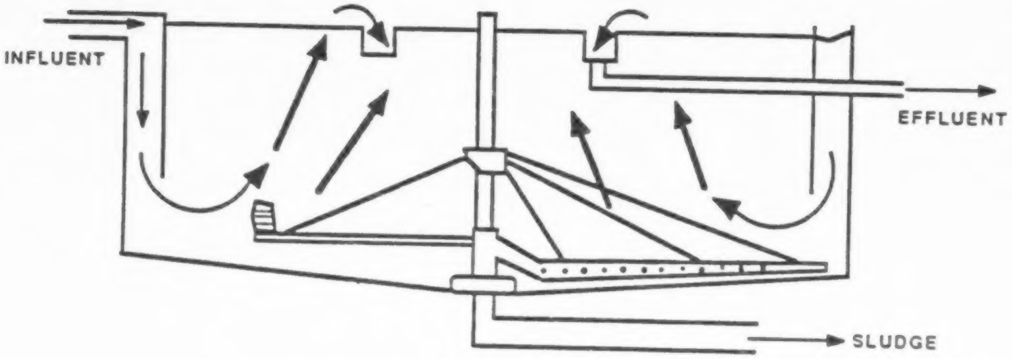
After the waste is reacted with the treatment chemical, it flows to a quiescent tank where the precipitate is allowed to settle and subsequently be removed. Settling can be chemically assisted through the use of flocculating compounds. Flocculants increase the particle size and density of the precipitated solids, both of which increase the rate of settling. The particular flocculating agent that will best improve settling characteristics will vary depending on the particular waste; the flocculating agent is generally selected by performing laboratory bench tests. Settling can be conducted in a large tank by relying solely on gravity, or it can be mechanically assisted through the use of a circular clarifier or an inclined separator. Schematics of the latter two separators are shown in Figures 3-8 and 3-9.

Filtration can be used for further removal of precipitated residuals both in cases where the settling system is underdesigned and in cases where the particles are difficult to settle. Polishing filtration is discussed in a separate technology section.

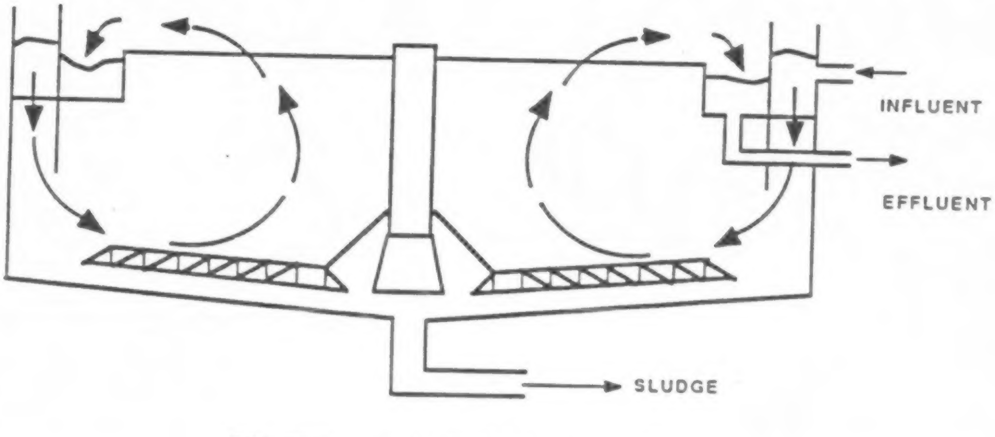
(4) Waste characteristics affecting performance. In determining whether chemical precipitation is likely to achieve the same level of performance on an untested waste as on a previously tested waste, EPA will examine the following waste characteristics: (a) the concentration and type of the metal(s) in the waste, (b) the concentration of total


EFFLUENT
SLUDGE
INFLUENT

CENTER FEED CLARIFIER WITH SCRAPER SLUDGE REMOVAL SUSTEM


INFLUENT
EFFLUENT
SLUDGE

RIM FEED - CENTER TAKEOFF CLARIFIER WITH
HYDRAULIC SUCTION SLUDGE REMOVAL SYSTEM


INFLUENT
EFFLUENT
SLUDGE

RIM FEED - RIM TAKEOFF CLARIFIER

FIGURE
CIRCULAR CLARIFIERS

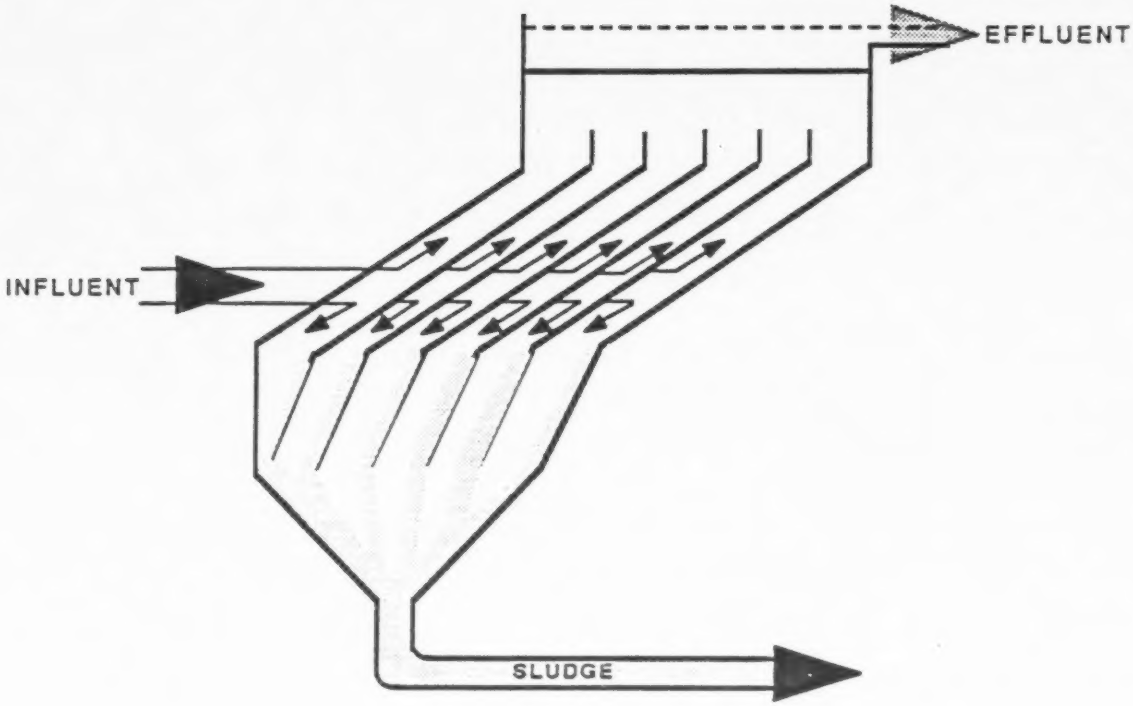

EFFLUENT
INFLUENT
SLUDGE

FIGURE
INCLINED PLATE SETTLER

suspended solids (TSS), (c) the concentration of total dissolved solids (TDS), (d) whether the metal exists in the wastewater as a complex, and (e) the oil and grease content. These parameters affect the chemical reaction of the metal compound, the solubility of the metal precipitate, or the ability of the precipitated compound to settle.

(a) Concentration and type of metals. For most metals, there is a specific pH at which the metal hydroxide is least soluble. As a result, when a waste contains a mixture of many metals, it is not possible to operate a treatment system at a single pH that is optimal for the removal of all metals. The extent to which this affects treatment depends on the particular metals to be removed and their concentrations. An alternative can be to operate multiple precipitations, with intermediate settling, when the optimum pH occurs at markedly different levels for the metals present. The individual metals and their concentrations can be measured using EPA Method 6010.

(b) Concentration and type of total suspended solids (TSS). Certain suspended solid compounds are difficult to settle because of either particle size or shape. Total suspended solids can be measured by EPA Wastewater Test Method 160.2.

(c) Concentration of total dissolved solids (TDS). Available information shows that total dissolved solids can inhibit settling. The literature states that poor flocculation may be a consequence of high TDS and shows that higher concentrations of total suspended solids are found in treated residuals. Poor flocculation may adversely affect the degree to which precipitated particles are removed. Total dissolved solids can be measured by EPA Wastewater Test Method 160.1.

(d) Complexed metals. Metal complexes consist of a metal ion surrounded by a group of other inorganic or organic ions or molecules (often called ligands). In the complexed form, the metals have a greater solubility and, therefore, may not be as effectively removed from solution by chemical precipitation. EPA does not have an analytical method to determine the amount of complexed metals in the waste. The Agency believes that the best measure of complexed metals is to analyze for some common complexing compounds (or complexing agents) generally found in wastewater for which analytical methods are available. These complexing agents include ammonia, cyanide, and EDTA. The analytical method for cyanide is EPA Method 9010. The method for EDTA is ASTM Method D3113. Ammonia can be analyzed using EPA Wastewater Test Method 350.

(e) Oil and grease content. The oil and grease content of a particular waste can directly inhibit the settling of the precipitate. Suspended oil droplets float in water and tend to suspend particles such as chemical precipitates that would otherwise settle out of the solution. Even with the use of coagulants or flocculants, the separation of the precipitate can be less effective. Oil and grease content can be measured by EPA Method 9071.

(5) Design and operating parameters. The parameters that EPA will evaluate when determining whether a chemical precipitation system is well designed and well operated are (a) design value for treated metal concentrations, as well as other characteristics of the waste used for design purposes (e.g., total suspended solids), (b) pH, (c) residence time, (d) choice of treatment chemical, (e) choice of coagulant/flocculant, and (f) mixing.

(a) Treated and untreated design concentrations. EPA pays close attention to the treated concentration that the system is designed to achieve when determining whether to sample a particular facility. Since the system will seldom outperform its design, EPA must evaluate whether the design is consistent with best demonstrated practice.

The untreated concentrations that the system is designed to treat are important in evaluating any treatment system. Operation of a chemical precipitation treatment system with untreated waste concentrations in excess of design values can easily result in poor performance.

(b) pH. The pH is important because it can indicate that sufficient treatment chemical (e.g., lime) has been added to convert the metal constituents in the untreated waste to forms that will precipitate. The pH also affects the solubility of metal hydroxides and sulfides and therefore directly impacts the effectiveness of removal. In practice, the design pH is determined by empirical bench testing, often referred to as "jar" testing. The temperature at which the "jar" testing is conducted is important in that it also affects the solubility of the metal precipitates. Operation of a treatment system at temperatures above the design temperature can result in poor performance. In assessing the operation of a chemical precipitation system, EPA prefers continuous data on the pH and periodic temperature conditions throughout the treatment period.

(c) Residence time. The residence time is important because it impacts the completeness of the chemical reaction to form the metal precipitate and, to a greater extent, the amount of precipitate that settles out of solution. In practice, it is determined by "jar" testing. For continuous systems, EPA will monitor the feed rate to ensure that the system is operated at design conditions. For batch systems, EPA will want information on the design parameter used to determine sufficient settling time (e.g., total suspended solids).

(d) Choice of treatment chemical. A choice must be made as to what type of precipitating agent (i.e., treatment chemical) will be used. The factor that most affects this choice is the type of metal constituents to be treated. Other design parameters, such as pH, residence time, and choice of coagulant/flocculant agents, are based on the selection of the treatment chemical.

(e) Choice of coagulant/flocculant. This is important because these compounds improve the settling rate of the precipitated metals and allow for smaller systems (i.e., lower retention time) to achieve the same degree of settling as much larger systems. In practice, the choice of the best agent and the required amount is determined by "jar" testing.

(f) Mixing. EPA will consider whether mixing is provided and whether the type of mixing device is one that could be expected to achieve uniform mixing.

3.4.2 Sludge Filtration

(1) Applicability. Sludge filtration, also known as sludge dewatering or cake-formation filtration, is a technology used on wastes that contain high concentrations of suspended solids, generally higher than 1 percent. Sludge filtration is applied to sludges, typically those that have settled to the bottom of clarifiers, for dewatering. After filtration, these sludges can be dewatered to 20 to 50 percent solids.

(2) Underlying principles of operation. The basic principle of filtration is the separation of particles from a mixture of fluids and particles by a medium that permits the flow of the fluid but retains the particles. As would be expected, larger particles are easier to separate from the fluid than smaller particles. Extremely small particles may not be filtered effectively and may appear in the treated waste. To mitigate this problem, the wastewater should be treated prior to filtration to modify the particle size distribution in favor of the larger particles, by the use of appropriate precipitants, coagulants, flocculants, and filter aids. The selection of the appropriate precipitant or coagulant is important because it affects the size of the particles formed. For example, lime precipitation usually produces larger, less gelatinous particles than does caustic soda precipitation. The use of coagulants and flocculants can also affect particle size.

(3) Physical description of the process. For sludge filtration, settled sludge is either pumped through a cloth-type filter medium (such as in a plate and frame filter) that allows solid "cake" to build up on the medium or drawn by vacuum through a cloth medium (such as on a drum or vacuum filter) that also allows the solids to build. In both cases, the solids themselves act as a filter for subsequent solids removal. For a plate and frame-type filter, removal of the solids is accomplished by taking the unit off line, opening the filter, and scraping the solids off. For the vacuum-type filter, cake is removed continuously. For a specific sludge, the plate and frame-type filter will usually produce a drier cake than a vacuum filter. Other types of sludge filters, such as belt filters, are also used for effective sludge dewatering.

(4) Waste characteristics affecting performance. The following characteristics of the waste will affect performance of a sludge filtration unit: (a) size of particles and (b) type of particles.

(a) Size of particles. The smaller the particle size, the more the particles tend to go through the filter medium. This is especially true for a vacuum filter. For a pressure filter (such as a plate and frame), smaller particles may require higher pressures for equivalent throughput since the smaller pore spaces between particles create resistance to flow.

(b) Type of particles. Some solids formed during metal precipitation are gelatinous in nature and cannot be dewatered well by cake-formation filtration. In fact, for vacuum filtration a cake may not form at all. In most cases, solids can be made less gelatinous by use of the appropriate coagulants and coagulant dosage prior to clarification, or after clarification but prior to filtration. In addition, the use of lime instead of caustic soda in metal precipitation will reduce the formation of gelatinous solids. Also, the addition of filter aids, such as lime or diatomaceous earth, to a gelatinous sludge will help significantly. Finally, precoating the filter with diatomaceous earth prior to sludge filtration will assist in dewatering gelatinous sludges.

(5) Design and operating parameters. For sludge filtration, the following design and operating variables affect performance: (a) type of filter selected, (b) size of filter selected, (c) feed pressure, and (d) use of coagulants or filter aids.

(a) Type of filter. Typically, a pressure-type filter (such as a plate and frame) will yield a drier cake than a vacuum-type filter and will also be more tolerant of variations in influent sludge characteristics. Pressure-type filters, however, are batch operations, so that when cake is built up to the maximum depth physically possible (constrained by filter geometry), or to the maximum design pressure, the filter is turned off while the cake is removed. A vacuum filter is a continuous device (i.e., cake discharges continuously), and will usually be much larger than a pressure filter with the same capacity. A hybrid device is a belt filter, which mechanically squeezes sludge between two continuous fabric belts.

(b) Size of filter. As with in-depth filters, the larger the filter, the greater its hydraulic capacity and the longer the filter runs between cake discharges.

(c) Feed pressure. This parameter impacts both the design pore size of the filter and the design flow rate. It is important that the design feed pressure not be exceeded; otherwise, particles may be forced through the filter medium, resulting in ineffective treatment.

(d) Use of coagulants. Coagulants and filter aids may be mixed with filter feed prior to filtration. Their effect is particularly significant for vacuum filtration in that it may make the difference in a vacuum filter between no cake and a relatively dry cake. In a pressure filter, coagulants and filter aids will also significantly improve hydraulic capacity and cake dryness. Filter aids, such as diatomaceous earth, can be precoated on filters (vacuum or pressure) for sludges that are particularly difficult to filter. The precoat layer acts somewhat like an in-depth filter in that sludge solids are trapped in the precoat pore spaces. Use of precoats and most coagulants or filter aids significantly increases the amount of sludge solids to be disposed of; however, polyelectrolyte coagulant usage usually does not increase sludge volume significantly because the dosage is low.

3.4.4 Polishing Filtration

Filtration is the removal of solids from wastes by a medium that permits the flow of the fluid but retains the particles. When filtration is conducted on wastewaters with low concentrations of solid particles (generally below 1,000 ppm), the term "polishing" filtration is applied; when conducted on wastes with higher concentrations of solids, the term "sludge" filtration is applied. This section discusses "polishing" filtration; sludge filtration is discussed separately.

(1) Applicability. Polishing filtration is used to treat wastewaters containing relatively low concentrations of solids. Multimedia filtration, pressure or gravity sand filtration, and cartridge filtration are some of the types of polishing filtration. This type of filtration is typically used as a polishing step for the supernatant after precipitation and settling (clarification) of wastewaters containing metal precipitates. In general, filtration is used to remove particles that are difficult to settle because of shape and/or density or to assist in removal of precipitated particles from an underdesigned settling device.

(2) Underlying Principle of Operation. The basic principle of filtration is the separation of particles from a mixture of fluids and particles by a medium that permits the flow of the fluid but retains the particles. As would be expected, larger particles are easier to separate from the fluid that smaller particles.

Extremely small particles, in the collodial range, may not be filtered effectively in a polishing filtration and may appear in the treated wastewater. To mitigate this problem, the wastewater should be treated prior to filtration to modify the particle size distribution in favor of the larger particles, by the use of appropriate precipitants, coagulants, flocculants, and filter aids. The selection of the appropriate precipitant or coagulant is important because it affects the particles formed. For example, lime neutralization usually produces larger, less gelatinous particles than does caustic soda precipitation.

Filter aids such as diatomaceous earth are used to precoat the cloth-type filter material and provide an initial filter cake onto which additional solids will be deposited during the filtration process. The presence of the precoat allows for removal of small particles from the solution being filtered. Smaller particles will mechanically adhere to the precoat solids during the filtration process.

(3) Description of Polishing Filtration System. For relatively low flows, a cartridge filter can be used. In this case a cylindrically shaped cartridge, such as a matted cloth, is placed within a sealed metal vessel. Wastewater is pumped through the cartridge until the flow drops excessively because of plugging of the filter media. The sealed vessel is then opened and the plugged cartridge removed and replaced with a new cartridge. The plugged cartridge is then disposed.

For relatively large volume flows, a granulated media (such as sand or anthracite coal) are used to trap suspended solids within the pore spaces of the media. Wastewater is filtered until excessive pressure is required to maintain the flow or until the flow drops to an unacceptable level. Granular media filters are cleaned, by backwashing with filtered water that has been stored for that purpose. (Backwashing is always upflow to loosen the media granuals and resuspend the entrapped solids.) The backwash water, which may be as much as 10 percent of the volume of the filtered wastewater, is then returned to the treatment system, so that the solids in the backwash water can be settled in the system clarifier.

(4) Waste Characteristics Affecting Performance. To determine whether filtration would achieve a level of performance on an untested waste similar to that of a tested waste, EPA will examine the following waste characteristics: (a) size of suspended particles and (b) type of particles.

(a) Size of particles. Extemely small particles, in the colloidal range, may not be filtered effectively in a polishing filter and may appear in the filtrate. Accordingly, EPA would examine the particle size in assessing transfer of performance. Particle size can be determined using ASTM Method D422, Particle Size Distribution.

(b) Particle type. Some suspended solids are gelatinous in nature and are, therefore, difficult to filter. To the extent possible, EPA will assess the type if suspended solid particles that are present in assessing transfer of performance. EPA is not aware of any specific quantitative method to measure the particle type; accordingly, such an assessment will be based on a qualitative engineering analysis of the suspended solid particles.

(5) Design and Operating Parameters. The design and operating parametes that EPA will evaluate in assessing the performance of polishing filtration (a) treated and untreated design concentrations, (b) type of filter, (c) pore size, (d) waste feed pressure, and (e) use and type of filter aids. Each of these parameters is discussed below.

(a) Treated and untreated design concentrations. As with other technologies, it is important to know the level of performance that the particular unit was designed to achieve in order to ensure that the design value represents best demonstrated practice. Additionally, EPA would want to evaluate feed characteristics to the filter during treatment to ensure that the unit was operated within design specifications. Operation of the filter in excess of feed conditions could easily lead to poor performance.

4. TREATMENT PERFORMANCE DATA BASE

This section presents all data available to EPA on the performance of the demonstrated technologies discussed in Section 3 for treating F006-F012 and F019 wastes. These data are used elsewhere in this document for determining which technologies represent BDAT (Section 5), for selecting constituents to be regulated (Section 6), and for developing the proposed treatment standards (Section 7). In addition to full-scale demonstration data, available data may include data developed at research facilities, or through other applications at less than full-scale operation, as long as the technology is demonstrated in full-scale operation for a similar waste or wastes as defined in Section 3.

Performance data include the untreated and treated waste concentrations for a given constituent, the values of operating parameters that were measured at the time the waste was being treated, the values of relevant design parameters for the treatment technology, and data on waste characteristics that affect performance of the treatment technology. EPA has provided all such data, to the extent that they are available, in the tables found at the end of this section.

Where data are not available on the treatment of the specific wastes of concern, the Agency may elect to transfer data on the treatment of a similar waste or wastes using a demonstrated technology. To transfer data from another waste category, EPA must find that the wastes covered by this background document are no more difficult to treat (based on the waste characteristics that affect performance of the demonstrated treatment technology) than the treated wastes from which performance data are being transferred.

4.1 Electrolytic Oxidation/Alkaline Chlorination Data

At Plant A, the Agency collected one set of untreated and treated F011 waste samples from a batch treatment system that consisted of electrolytic oxidation, alkaline chlorination, chemical precipitation, filtration, and sludge dewatering (shown as Sample Set No. 1 in Table 4-1). The Agency also collected one set of samples from treatment of heat treating quenching wastewaters by the same treatment system as above except for the electrolytic oxidation step (shown as Sample Set No. 2 in Table 4-1). These data show, along with design and operating information, the total concentrations of metals and cyanide in the untreated waste. This treated wastewater (after precipitation of metals and filtration for removal of suspended solids), the precipitated solids from chemical precipitation, treated further by sludge dewatering, and the total and also the TCLP leachate concentrations of metals in the treated nonwastewater and cyanide in the treated nonwastewater.

4.2 Wet Air Oxidation Data

In an EPA test at Plant B, the Agency collected six sets of data for untreated and treated F007 waste using a pilot-scale wet air oxidation treatment system. These data, presented in Table 4-2, show, along with design and operating information, the total concentration of metals and cyanide in the untreated waste, the treated wastewater, and the treated nonwastewater, as well as the TCLP leachate concentrations of metals in the nonwastewater treatment residual (reactor wall scale and reactor bottom solids).

4.3 Alkaline Chlorination Data

The Agency reviewed data submitted by Plant C on treatment of a variety of cyanide wastes by batch alkaline chlorination (CyanoKEM 1987). These data, for eight sample sets, are presented in Table 4-3. The data show concentrations of total cyanide in the untreated waste and amenable cyanide in the treated wastewater, as well as design and operating information for each test.

The Agency also collected two sets of treatment data at Plant E, presented in Table 4-7. These data show total cyanide concentrations for both the influent and the effluent from alkaline chlorination treatment (USEPA 1985).

4.4 Electrolytic Oxidation Data

Table 4-4 presents 11 data sets obtained from the literature on the performance of electrolytic oxidation treatment of cyanide wastes (Easton 1967). The data show cyanide concentrations in the untreated and treated wastewater, as well as design and operating information obtained during the tests.

4.5 High-Temperature Cyanide Hydrolysis Data

Table 4-5 presents six data sets obtained from the literature from full-scale testing of high-temperature cyanide hydrolysis (Robey 1983). These data present cyanide concentrations in the untreated and treated wastes as well as operating data for each test. Wastes tested were actual F007-F009 electroplating wastes, in the form of both bulk liquids (wastewaters) and drummed solids (nonwastewaters).

4.6 Chemical Precipitation Data

The data for BDAT metals from Plant A, shown in Table 4-1, show treatment of metals in wastewater by chemical precipitation followed by filtration and sludge dewatering. Additionally, the Agency has data for chromium reduction followed by chemical precipitation, filtration, and sludge dewatering for treatment of K062 and other wastes. (See EPA's BDAT Background Document for K062 (USEPA 1988b).)

4.7 Stabilization Data

The Agency has data on treatment of BDAT list metals in F006 waste by stabilization. (See EPA's BDAT Background Document for F006 (USEPA 1988a)). EPA has not identified any metals treatment data for F012 or F019 wastes other than the data considered in developing treatment standards for F006, for which stabilization was determined to be BDAT.

4.8 Incineration Data

Plant D submitted two data sets on treatment of F010 waste and a similar waste by incineration, presented in Table 4-6 (CyanoKEM 1988). These data show total cyanide concentration in both the untreated waste and the treated solid residual (ash). No data were presented for the scrubber water.

4.9 Other Agency Data on Cyanide Treatment

The Agency has examined the data used for development of the effluent limitations guidelines for the metal finishing point source category and all data identified for cyanide treatment in the Notice of Availability for California List Constituents (52 FR 29991, August 12, 1987). All cyanide treatment data from the above-listed sources not discussed in this section had untreated waste cyanide concentrations much lower than for the treatment data that are presented in Tables 4-1 through 4-7.

Table 4-1 Electrolytic Oxidation, Alkaline Chlorination, Chemical Precipitation, and Sludge Dewatering Data Collected by EPA at Plant A for Treatment of F011 and Heat Treating Quenching Wastewaters

Sample Set No. 1[a]

	Concentration			
	Untreated waste	Treated wastewater	Treated nonwastewater	
Constituent	Total (mg/l)	Total (mg/l)	Total (mg/kg)	TCLP (mg/l)
Antimony	0.029	<0.021	<2.1	<0.021
Barium	1.0	0.084	19	0.301
Cadmium	0.01	<0.004	1.4	0.016
Chromium (hexavalent)	<0.01	8.95	-	0.259
Chromium (total)	5.42	6.55	39	0.236
Copper	1.03	0.043	72	0.076
Lead	1.1	<0.05	22	0.011
Mercury	<0.00025	0.00022	<0.10	<0.0002
Nickel	2.88	0.58	519	3.06
Silver	0.0072	0.012	<0.20	<0.002
Vanadium	0.156	0.032	7.0	0.014
Zinc	0.338	0.03	31	0.352
Cyanide (amenable)	I	3.0 [b]	19.9	-
Cyanide (total)	5,350	117 [b]	99.4	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Electrolytic oxidation reactor temperature	170-180°F	175-180°F
Electrolytic oxidation reactor pH	>11.0	10.6-11.6
Alkaline chlorination reactor pH (2-step)	>11.0; 7.0-9.0	11.2; 8.0
Excess chlorine in alkaline chlorination reactor	NS	30 mg/l

I = Sample result is indeterminate because of analytical interference, but is less than 5,130 mg/l based on laboratory analysis of total and amenable cyanides for the partially treated waste.

- = Not analyzed.

NS = Not specified.

[a] Electrolytic oxidation was used only with Sample Set No. 1.

[b] Accuracy-adjusted concentration.

Reference: USEPA 1988e.

Table 4-1 (continued)

Alkaline Chlorination, Chemical Precipitation, and Sludge Dewatering Data Collected by EPA at Plant A for Heat Treating Quenching Wastewaters

Sample Set No. 2

Constituent	Concentration			
	Untreated waste	Treated wastewater	Treated nonwastewater	
	Total (mg/l)	Total (mg/l)	Total (mg/kg)	TCLP (mg/l)
Antimony	<0.021	<0.021	<2.1	<0.021
Barium	0.158	0.102	98	0.312
Cadmium	0.057	0.0092	5.31	0.052
Chromium (hexavalent)	<0.01	0.625	-	0.436
Chromium (total)	0.175	1.63	11	0.31
Copper	1.08	0.035	307	0.354
Lead	0.063	<0.005	28	0.01
Mercury	<0.0002	0.00032	<0.1	<0.0002
Nickel	10.9	0.64	758	5.9
Silver	0.064	0.094	0.73	0.034
Vanadium	0.043	0.011	6.7	0.0061
Zinc	0.60	0.147	54	0.377
Cyanide (amenable)	29.2	<0.01	5.6	-
Cyanide (total)	62.6	<0.01	34.7	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Alkaline chlorination reactor pH	>11.0; 7.0-9.0	11.6; 7.6
Excess chlorine in alkaline chlorination reactor	NS	120 mg/l

- = Not analyzed.
NS = Not specified.

Table 4-2 Wet Air Oxidation Data Collected by EPA at Plant B for F007 Waste

Sample Set No. 1

	Concentration					
			Treated nonwastewater			
	Untreated waste	Treated wastewater	Reactor solids A[a]		Reactor solids B[b]	
Constituent	Total (mg/l)	Total (mg/l)	Total (mg/kg)	TCLP (mg/l)	Total (mg/kg)	TCLP (mg/l)
BDAT Organics						
Methanol	CBI	266	<15	-	<15	-
BDAT Inorganics						
Antimony	CBI	<4.0	<350	-	<35	-
Arsenic	CBI	<0.05	<1.0	<0.01	<1.0	<0.01
Barium	CBI	0.047	1.25	0.20	6.4	0.17
Beryllium	CBI	<0.075	<0.15	-	<1.5	-
Cadmium	CBI	<0.06	<1.25	<0.10	<1.0	<0.10
Chromium (hexavalent)	CBI	I	I	I	I	I
Chromium (total)	CBI	0.628	2.55	<0.10	6.09	<0.10
Copper	CBI	759	151,000	-	44,400	-
Lead	CBI	<1.75	<35	<2.0	<35	<2.0
Mercury	CBI	<0.015	<1.0	<0.05	<1.0	<0.05
Nickel	CBI	<0.25	33.7	-	26.5	-
Selenium	CBI	<0.045	<1.0	<0.01	<1.0	<0.01
Silver	CBI	<0.55	<10	<1.0	<8.0	<1.0
Thallium	CBI	<2.0	<40	-	<40	-
Vanadium	CBI	<0.125	<2.5	-	5.3	-
Zinc	CBI	7.91	29,600	-	139,000	-
Cyanide (amenable)	CBI	0.3	<25	-	<25	-
Cyanide (total)	CBI	11.9	<25	-	<25	-
Fluoride	CBI	4.20	-	-	-	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Reactor temperature	440-480°F	449-487°F
Residence time	55-66 min (5.0-6.0 gal/hr)	57.1 min
Oxygen concentration (off-gas)	16-20%	17.8%
Reactor pressure	1700 psig	1690-1707 psig

I = Matrix interference.

- = Not analyzed.

[a] Reactor wall scale; one sample collected for all six sample sets.

[b] Reactor bottom solids; one sample collected for all six sample sets.

Reference: USEPA 1988f.

Table 4-2 (continued)

Sample Set No. 2

	Concentration					
			Treated nonwastewater			
	Untreated waste	Treated wastewater	Reactor solids A[a]		Reactor solids B[b]	
Constituent	Total (mg/l)	Total (mg/l)	Total (mg/kg)	TCLP (mg/l)	Total (mg/kg)	TCLP (mg/l)
BDAT Organics						
Methanol	CBI	<150	<15	-	<15	-
BDAT Inorganics						
Antimony	CBI	<4.0	<350	-	<35	-
Arsenic	CBI	<0.05	<1.0	<0.01	<1.0	<0.01
Barium	CBI	<0.03	1.25	0.20	6.4	0.17
Beryllium	CBI	<0.075	<0.15	-	<1.5	-
Cadmium	CBI	0.17	<1.25	<0.10	<1.0	<0.10
Chromium (hexavalent)	CBI	I	I	I	I	I
Chromium (total)	CBI	0.478	2.55	<0.10	6.09	<0.10
Copper	CBI	568	151,000	-	44,400	-
Lead	CBI	<1.75	<35	<2.0	<35	<2.0
Mercury	CBI	<0.015	<1.0	<0.05	<1.0	<0.05
Nickel	CBI	<0.25	33.7	-	26.5	-
Selenium	CBI	<0.045	<1.0	<0.01	<1.0	<0.01
Silver	CBI	<0.55	<10	<1.0	<8.0	<1.0
Thallium	CBI	<2.0	<40	-	<40	-
Vanadium	CBI	<0.125	<2.5	-	5.3	-
Zinc	CBI	7.48	29,600	-	139,000	-
Cyanide (amenable)	CBI	<0.25	<25	-	<25	-
Cyanide (total)	CBI	<0.25	<25	-	<25	-
Fluoride	CBI	4.02	-	-	-	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Reactor temperature	440-480°F	440-489°F
Residence time	55-66 min (5.0-6.0 gal/hr)	60.5 min
Oxygen concentration (off-gas)	16-20%	17.0%
Reactor pressure	1700 psig	1709-1725 psig

I = Matrix interference.
- = Not analyzed.

[a] Reactor wall scale; one sample collected for all six sample sets.

[b] Reactor bottom solids; one sample collected for all six sample sets.

Table 4-2 (continued)

Sample Set No. 3

	Concentration					
			Treated nonwastewater			
	Untreated waste	Treated wastewater	Reactor solids A[a]		Reactor solids B[b]	
Constituent	Total (mg/l)	Total (mg/l)	Total (mg/kg)	TCLP (mg/l)	Total (mg/kg)	TCLP (mg/l)
BDAT Organics						
Methanol	CBI	110	<15	-	<15	-
BDAT Inorganics						
Antimony	CBI	<4.0	<350	-	<35	-
Arsenic	CBI	<0.05	<1.0	<0.01	<1.0	<0.01
Barium	CBI	0.038	1.25	0.20	6.4	0.17
Beryllium	CBI	<0.075	<0.15	-	<1.5	-
Cadmium	CBI	0.48	<1.25	<0.10	<1.0	<0.10
Chromium (hexavalent)	CBI	I	I	I	I	I
Chromium (total)	CBI	0.568	2.55	<0.10	6.09	<0.10
Copper	CBI	834	151,000	-	44,400	-
Lead	CBI	<1.75	<35	<2.0	<35	<2.0
Mercury	CBI	<0.015	<1.0	<0.05	<1.0	<0.05
Nickel	CBI	<0.25	33.7	-	26.5	-
Selenium	CBI	<0.045	<1.0	<0.01	<1.0	<0.01
Silver	CBI	<0.55	<10	<1.0	<8.0	<1.0
Thallium	CBI	<2.0	<40	-	<40	-
Vanadium	CBI	<0.125	<2.5	-	5.3	-
Zinc	CBI	4.63	29,600	-	139,000	-
Cyanide (amenable)	CBI	<0.25	<25	-	<25	-
Cyanide (total)	CBI	3.22	<25	-	<25	-
Fluoride	CBI	4.02	-	-	-	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Reactor temperature	440-480°F	431-488°F
Residence time	55-66 min (5.0-6.0 gal/hr)	59.2 min
Oxygen concentration (off-gas)	16-20%	17.5%
Reactor pressure	1700 psig	1701-1718 psig

I = Matrix interference.
- = Not analyzed.

[a] Reactor wall scale; one sample collected for all six sample sets.

[b] Reactor bottom solids; one sample collected for all six sample sets.

Table 4-2 (continued)

Sample Set No. 4

	Concentration					
			Treated nonwastewater			
	Untreated waste	Treated wastewater	Reactor solids A[a]		Reactor solids B[b]	
Constituent	Total (mg/l)	Total (mg/l)	Total (mg/kg)	TCLP (mg/l)	Total (mg/kg)	TCLP (mg/l)
BDAT Organics						
Methanol	CBI	64	<15	-	<15	-
BDAT Inorganics						
Antimony	CBI	<4.0	<350	-	<35	-
Arsenic	CBI	<0.05	<1.0	<0.01	<1.0	<0.01
Barium	CBI	<0.30	1.25	0.20	6.4	0.17
Beryllium	CBI	<0.75	<0.15	-	<1.5	-
Cadmium	CBI	<0.60	<1.25	<0.10	<1.0	<0.10
Chromium (hexavalent)	CBI	I	I	I	I	I
Chromium (total)	CBI	<0.90	2.55	<0.10	6.09	<0.10
Copper	CBI	766	151,000	-	44,400	-
Lead	CBI	<17.5	<35	<2.0	<35	<2.0
Mercury	CBI	<0.015	<1.0	<0.05	<1.0	<0.05
Nickel	CBI	<2.5	33.7	-	26.5	-
Selenium	CBI	<0.045	<1.0	<0.01	<1.0	<0.01
Silver	CBI	<5.5	<10	<1.0	<8.0	<1.0
Thallium	CBI	<20	<40	-	<40	-
Vanadium	CBI	<1.25	<2.5	-	5.3	-
Zinc	CBI	6.26	29,600	-	139,000	-
Cyanide (amenable)	CBI	<0.25	<25	-	<25	-
Cyanide (total)	CBI	<0.25	<25	-	<25	-
Fluoride	CBI	4.07	-	-	-	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Reactor temperature	440-480°F	424-493°F
Residence time	55-66 min (5.0-6.0 gal/hr)	53.3 min
Oxygen concentration (off-gas)	16-20%	16.5%
Reactor pressure	1700 psig	1675-1740 psig

I = Matrix interference.

- = Not analyzed.

[a] Reactor wall scale; one sample collected for all six sample sets.

[b] Reactor bottom solids; one sample collected for all six sample sets.

Table 4-2 (continued)

Sample Set No. 5

	Concentration					
			Treated nonwastewater			
	Untreated waste	Treated wastewater	Reactor solids A[a]		Reactor solids B[b]	
Constituent	Total (mg/l)	Total (mg/l)	Total (mg/kg)	TCLP (mg/l)	Total (mg/kg)	TCLP (mg/l)
BDAT Organics						
Methanol	CBI	50	<15	-	<15	-
BDAT Inorganics						
Antimony	CBI	<4.0	<350	-	<35	-
Arsenic	CBI	<0.05	<1.0	<0.01	<1.0	<0.01
Barium	CBI	<0.03	1.25	0.20	6.4	0.17
Beryllium	CBI	<0.075	<0.15	-	<1.5	-
Cadmium	CBI	<0.72	<1.25	<0.10	<1.0	<0.10
Chromium (hexavalent)	CBI	I	I	I	I	I
Chromium (total)	CBI	0.499	2.55	<0.10	6.09	<0.10
Copper	CBI	946	151,000	-	44,400	-
Lead	CBI	<1.75	<35	<2.0	<35	<2.0
Mercury	CBI	<0.015	<1.0	<0.05	<1.0	<0.05
Nickel	CBI	<0.25	33.7	-	26.5	-
Selenium	CBI	<0.045	<1.0	<0.01	<1.0	<0.01
Silver	CBI	<0.55	<10	<1.0	<8.0	<1.0
Thallium	CBI	<2.0	<40	-	<40	-
Vanadium	CBI	<0.125	<2.5	-	5.3	-
Zinc	CBI	4.07	29,600	-	139,000	-
Cyanide (amenable)	CBI	<0.25	<25	-	<25	-
Cyanide (total)	CBI	<0.25	<25	-	<25	-
Fluoride	CBI	4.06	-	-	-	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Reactor temperature	440-480°F	417-484°F
Residence time	55-66 min (5.0-6.0 gal/hr)	51.6 min
Oxygen concentration (off-gas)	16-20%	16.6%
Reactor pressure	1700 psig	1680-1694 psig

I = Matrix interference.

- = Not analyzed.

[a] Reactor wall scale; one sample collected for all six sample sets.

[b] Reactor bottom solids; one sample collected for all six sample sets.

Table 4-2 (continued)

Sample Set No. 6

	Concentration					
			Treated nonwastewater			
	Untreated waste	Treated wastewater	Reactor solids A[a]		Reactor solids B[b]	
Constituent	Total (mg/l)	Total (mg/l)	Total (mg/kg)	TCLP (mg/l)	Total (mg/kg)	TCLP (mg/l)
BDAT Organics						
Methanol	CBI	36	<15	-	<15	-
BDAT Inorganics						
Antimony	CBI	<4.0	<350	-	<35	-
Arsenic	CBI	<0.05	<1.0	<0.01	<1.0	<0.01
Barium	CBI	<0.6	1.25	0.20	6.4	0.17
Beryllium	CBI	<1.5	<0.15	-	<1.5	-
Cadmium	CBI	<1.2	<1.25	<0.10	<1.0	<0.10
Chromium (hexavalent)	CBI	I	I	I	I	I
Chromium (total)	CBI	<1.8	2.55	<0.10	6.09	<0.10
Copper	CBI	994	151,000	-	44,400	-
Lead	CBI	<35	<35	<2.0	<35	<2.0
Mercury	CBI	<0.015	<1.0	<0.05	<1.0	<0.05
Nickel	CBI	<5.0	33.7	-	26.5	-
Selenium	CBI	<0.045	<1.0	<0.01	<1.0	<0.01
Silver	CBI	<11	<10	<1.0	<8.0	<1.0
Thallium	CBI	<40	<40	-	<40	-
Vanadium	CBI	<2.5	<2.5	-	5.3	-
Zinc	CBI	8.46	29,600	-	139,000	-
Cyanide (amenable)	CBI	<0.25	<25	-	<25	-
Cyanide (total)	CBI	<0.25	<25	-	<25	-
Fluoride	CBI	3.95	-	-	-	-

Note: Design and operating parameters are as follows:

Parameter	Design value	Operating value
Reactor temperature	440-480°F	412-494°F
Residence time	55-66 min (5.0-6.0 gal/hr)	50.8 min
Oxygen concentration (off-gas)	16-20%	17.0%
Reactor pressure	1700 psig	1674-1690 psig

[a] Reactor wall scale; one sample collected for all six sample sets.

[b] Reactor bottom solids; one sample collected for all six sample sets.

I = Matrix interference.

- = Not analyzed.

Table 4-4 Electrolytic Oxidation Treatment Data from Literature Source A for Treatment of F007 and F009 Wastes

Constituent	Concentration (units) Untreated waste (mg/l)	 Treated wastewater (mg/l)	Reaction time (days)
Sample Set #1:			
Cyanide (total)	95,000	0.1	16
Sample Set #2:			
Cyanide (total)	75,000	0.2	17
Sample Set #3:			
Cyanide (total)	50,000	0.4	10
Sample Set #4:			
Cyanide (total)	75,000	0.2	18
Sample Set #5:			
Cyanide (total)	65,000	0.2	12
Sample Set #6:			
Cyanide (total)	100,000	0.3	17
Sample Set #7:			
Cyanide (total)	55,000	0.4	14
Sample Set #8:			
Cyanide (total)	45,000	0.1	7
Sample Set #9:			
Cyanide (total)	50,000	0.4	14
Sample Set #10:			
Cyanide (total)	55,000	0.2	8
Sample Set #11:			
Cyanide (total)	48,000	0.4	12

Note: Design values for operating conditions are presented below:

Parameter	Value/Description
Temperature	200°F minimum
Total current	1,200 amp @ 6 volts
Anode current density	35 amp/ft^2

Reference: Easton 1967. Treatment of F007 and F009 copper plating wastes.

Table 4-5 High-Temperature Cyanide Hydrolysis Data from Literature Source B for Treatment of F007, F008, and F009 Wastes

Constituent	Concentration (units)		Operating Data (units)		
	Untreated waste (mg/l)	Treated wastewater (mg/l)	Maximum temperature (°F)	Maximum pressure (psi)	Reaction time at maximum temperature (hr)
Sample Set No. 1:					
Cyanide (total)	10,000	19.8	477	700	1 hr
Sample Set No. 2:					
Cyanide (total)	30,000	0.8	492	875	1 hr
Sample Set No. 3:					
Cyanide (total)	10,000	2.6	450	-[a]	1 hr
Sample Set No. 4:					
Cyanide (total)	10,000	15	460	620	1 hr
Sample Set No. 5:					
Cyanide (total)	33,000	1.2	500	875	1 hr
Sample Set No. 6:					
Cyanide (total)	38,000	2.1	458	875	1 hr

[a] Pressure gauge malfunction; 875 psi is assumed.

Reference: Robey 1983. Treatment of F007-F009 wastes containing cadmium, copper, and/or nickel cyanides.

Table 4-6 Incineration Data Submitted by Plant D for Treatment of F010

	Concentration (units)	
	Untreated waste	Treated nonwastewater (total) (mg/kg)
Sample Set No. 1:		
Cyanide (total)	-[a]	0.45
Sample Set No. 2:		
Cyanide (total)	-[a]	0.40
Sample Set No. 3:		
Cyanide (total)	-[a]	0.88

- = Not analyzed.

[a] = Note explaining that two wastes were mixed and treated together.

Reference: CyanoKEM 1988.

Table 4-8 Alkaline Chlorination Data Collected by EPA at Plant E

Constituent/parameter	Concentration (units) Untreated waste (mg/l)	Concentration (units) Treated wastewater (mg/l)
Sample Set No. 1		
Cyanide (total)	5,800	<5
Sample Set No. 2		
Cyanide (total)	11,000	<5

5. IDENTIFICATION OF BEST DEMONSTRATED AVAILABLE TECHNOLOGY (BDAT)

This section presents the Agency's rationale for determining best demonstrated available technology (BDAT) for F006 (cyanide), F007-F012, and F019 nonwastewaters and wastewaters. To determine BDAT, the Agency examines all available performance data for the technologies that are identified as demonstrated to determine whether one of these technologies performs significantly better than the others. All performance data used for determination of best technology must first be adjusted for accuracy, as discussed in EPA's publication, Methodology for Developing BDAT Treatment Standards.* BDAT must be specifically defined for all streams associated with the management of the listed waste or wastes; this includes the original waste as well as any residual waste streams created by the treatment process.

The technology that performs best on a particular waste or waste subcategory is then evaluated to determine whether it is "available." To be available, the technology must (1) be commercially available to any generator and (2) provide "substantial" treatment of the waste, as determined through evaluation of accuracy-adjusted data. In determining whether treatment is substantial, EPA may consider data on the performance of a waste similar to the waste in question, provided that the similar waste is at least as difficult to treat.

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* Accuracy adjustment accounts for the ability of an analytical technique to recover a particular constituent from the waste in a particular test. The recovery of a constituent is determined by spiking a sample with a known amount of the target constituent and then comparing the result of analysis of the spiked sample with the result from the unspiked sample.

5.1 BDAT for the Metal Finishing Aqueous Liquids Subcategory

5.1.1 Cyanide Treatment

EPA reviewed the available treatment performance data for wastes in this subcategory for cyanide treatment technologies, presented in Section 4, to determine whether they represent the operation of well-designed and well-operated systems, whether sufficient quality assurance/quality control (QA/QC) data were collected to assess the accuracy of the treated waste analyses, and whether the data presented provide the appropriate measure of performance for the technology tested.

The treatment performance data for electrolytic oxidation followed by alkaline chlorination collected at Plant A, presented in Table 4-1, provide the appropriate measure of performance for this technology (amenable and total cyanide concentrations in the untreated waste and in both the wastewater and nonwastewater residuals). Design and operating data collected during the test indicate that the system was well designed and was well operated during the test. Additionally, the appropriate QA/QC data were supplied with these performance data.

The treatment performance data for wet air oxidation of F007 waste, presented in Table 4-2, also provide amenable and total cyanide concentrations in the untreated waste and in both wastewater and nonwastewater residuals. The F007 waste tested had concentrations of total BDAT metals and total and amenable cyanide similar to the concentrations of these constituents found in other F007 wastes and in F008, F009, and F011 wastes (see Section 2.3 and Appendix B). Design and operating data collected during the test indicate that the system was well designed and was well operated during the collection of five of the six sets of performance data. The appropriate QA/QC data were supplied with these performance data. The data collected for Sample Set No. 1 show higher concentrations of both amenable and total cyanide in the feed (approximately 20 percent higher) than for any of the other five sample sets, without a corresponding increase in residence time. This may account for a poorer system performance, as shown by the data. This problem might have been alleviated in operation either by better mixing of the feed or by increasing the residence time (i.e., by decreasing the feed flow rate for higher concentration feed streams). The data for Sample Set No. 1 were not considered further in the development of BDAT standards on the basis of poor system operation (insufficient reactor residence time) at the time of treatment data collection.

Treatment performance data for alkaline chlorination submitted by Plant C, presented in Table 4-3, provide total cyanide concentration in the untreated waste and amenable cyanide concentration in the treated wastewater. The design and operating data submitted indicate that the system was well designed and was well operated during the tests. No QA/QC data were submitted.

Treatment performance data for electrolytic oxidation were obtained from literature source A and are presented in Table 4-4. These data provide total cyanide concentrations for both the untreated waste and the treated wastewater. The design values given indicate that the system was well designed, and the treated waste cyanide concentration, as well as the reaction time, indicates that the system was well operated at the time of treatment data collection. No QA/QC data were given for these tests.

Treatment performance data for high temperature cyanide hydrolysis were obtained from literature source B and are presented in Table 4-5. These data provide total cyanide concentrations for both the untreated waste and the treated wastewater after subsequent chemical precipitation treatment followed by filtration to remove suspended precipitated solids. No system design data were specified. The operating data provided indicate that the system was well operated during the collection of treatment data sets Nos. 2, 3, 5, and 6. For data sets No. 1 and No. 4, the operating data indicate that low reactor pressure (700 psi and 620 psi versus 875 psi for the other four runs) contributed to the higher effluent cyanide concentration; therefore, these data sets were not further considered in assessing the performance of this technology (based on poor operation). No QA/QC data were given for these tests.

The treatment performance data for the demonstrated cyanide treatment technologies presented in Section 4 were adjusted for analytical recovery to take into account analytical interferences associated with the chemical makeup of the treated waste samples. In the QA/QC test for analytical recovery, EPA first analyzes a waste for a constituent and then adds a known amount (i.e., a spike) of the same constituent to the waste material and reanalyzes the sample for that constituent. The difference between the total amount detected after spiking and the concentration detected in the unspiked sample divided by the amount of spike added is the recovery value. (If recovery tests are run in duplicate, EPA uses the lower recovery value.) The reciprocal of the recovery multiplied by the analytical value obtained during performance testing is the accuracy-corrected value used in comparing treatment effectiveness and subsequently in calculating treatment standards. Percent recovery values for constituents detected in the F007 and F011 wastes tested are presented in Appendix A. In the cases for which no analytical recovery data were available (Tables 4-3 through 4-5), EPA believes that QA/QC adjustment of the data was not performed. Therefore, the Agency cannot directly compare these data to the data for which accuracy correction factors are available. The data presented in Tables 4-3 through 4-5 for alkaline chlorination, electrolytic oxidation, and high-temperature cyanide hydrolysis were not considered in the determination of "best" treatment of cyanide in F007-F011 wastewaters and nonwastewaters.

Accuracy-adjusted cyanide concentrations for all data considered in developing BDAT for the metal finishing aqueous liquids subcategory (F007, F008, F009, F011) for wastewaters are presented in Tables 5-1 and 5-2 for amenable and total cyanide, respectively. (All tables are at the end of the section.) Statistical comparison of the one data set from electrolytic oxidation followed by alkaline chlorination with the five data sets from wet air oxidation from treatment of similar wastes shows that the performance of wet air oxidation is better for both amenable and total cyanides.

EPA's determination that substantial treatment occurs for wet air oxidation is based on the reduction in both total and amenable cyanide concentrations in the waste tested. In addition to providing substantial treatment, wet air oxidation is commercially available; therefore, this technology is "available" to treat cyanide in the wastes in the metal finishing aqueous liquids subcategory.

For this subcategory, the Agency believes that a well-operated and well-designed alkaline chlorination treatment process can achieve similar levels as wet air oxidation. The wastes or combinations of wastes that were treated by alkaline chlorination showed similar waste characteristics (e.g., initial concentration of cyanides) to those of the F007 that was treated by wet air oxidation. Based on conversions with treaters of cyanide waste by alkaline chlorination and the review of preliminary data (i.e., before accuracy adjustment), the Agency believes that alkaline chlorination, if well designed and well operated, can achieve similar performance levels for amenable and total cyanides.

5.1.2 BDAT List Metals Treatment

Characterization data for F007, F008, F009, and F011 wastes show that these wastes may contain high concentrations of dissolved metals and therefore may require treatment by chemical precipitation followed by filtration and sludge dewatering. Chromium reduction may also be necessary prior to chemical precipitation if the waste has a treatable concentration of hexavalent chromium following cyanide oxidation. This treatment train can be added after application of one of the demonstrated technologies for cyanide removal, and it results in a wastewater and nonwastewater treatment residual.

(1) Wastewaters. Data on the performance of chromium reduction followed by chemical precipitation and filtration for wastewaters were developed for regulation of K062 waste. Two data sets were also

presented, in Table 4-1, for chemical precipitation followed by filtration and sludge dewatering treatment of F011 waste mixed with heat treating rinsewaters. These two sets of performance data are not directly comparable because the K062 waste treated had significantly higher concentrations of BDAT list metals than the F011 waste treated. The treatment data used in regulation of K062 can be transferred to the wastewater residual from treatment of F007, F008, F009, F010 (inorganic subgroup), and F011 because these wastes have similar or lower dissolved metals concentrations and thus will treat similarly to K062, whereas the F011 treatment data represent treatment of a waste with significantly lower metals concentrations than expected for most F007, F008, F009, and F011 wastes and thus cannot be transferred. Because the K062 treatment data are the only data available to EPA on the performance level of chromium reduction followed by chemical precipitation and filtration treatment of a waste with high BDAT metals concentration, the Agency has determined that the performance of chromium reduction followed by chemical precipitation and filtration is "best" for treatment of BDAT list metals in these wastes following cyanide treatment. As was presented for K062 (see EPA's BDAT Background Document for K062), this technology is "available" and thus meets the Agency's criteria for BDAT.

(2) Nonwastewaters. The nonwastewater treatment residual from the chemical precipitation step, either before or after dewatering, is a waste that is similar to the wastes in the metal finishing sludges subcategory. The selection of BDAT for these wastes is the same as that for the metal finishing sludges subcategory discussed in the next section.

5.2 BDAT for the Metal Finishing Sludges Subcategory

5.2.1 BDAT List Metals Treatment

EPA has previously promulgated treatment standards for BDAT list metal constituents for F006 based on the performance of stabilization (see EPA's BDAT Background Document for F006). EPA believes that the wastes F012 and F019 are similar to F006 both in waste composition and in the process generating the waste. These wastes are also similar to the nonwastewater treatment residuals from treatment of F007-F009 and F011 wastes by chemical precipitation followed by filtration. Specifically, the types and concentrations of metals and inorganics in F006, F012, and F019 wastes, are similar. Also, substances such as oil and grease or sulfates, that interface with stabilization are not expected to be present in significant concentrations in these wastes. It follows, therefore, that since no data on treatment of F006 or similar wastes are available other than the data used to develop stabilization treatment standards for F006, stabilization represents the best treatment for BDAT list metals for F012, F019, and the nonwastewater residuals (i.e., wastewater treatment sludges) from chemical precipitation and sludge dewatering treatment of F007, F008, F009, and F011 based on the similarities discussed above between F006 and these wastes.

5.2.2 Cyanide Treatment

For cyanide, no data are available to the Agency on treatment of F006, F012, F019, or similar wastes by any of the technologies identified as demonstrated for F007, F008, F009, and F011. As stated in Section 2.4, however, these wastes are generated from chemical precipitation treatment, which usually follows a cyanide oxidation step if the waste treated originally contained cyanide. Therefore, these wastes are not expected to contain treatable concentrations of cyanide if generated following treatment by a well-designed and well-operated cyanide treatment step. The Agency has two data sets on the generation of F012 waste from a well-designed and well-operated treatment system consisting of electrolytic oxidation followed by alkaline chlorination, chemical precipitation, filtration, and sludge dewatering (presented in Table 4-1). The accuracy-adjusted data for cyanides in this waste as generated are presented in Table 5-3. Treatment of the waste for cyanide before generation of these wastes is the Agency's "best" technology for determination of cyanide treatment standards for F006, F012, F019, and similar wastes.

As discussed in Section 4 and previously in this section, alkaline chlorination, electrolytic oxidation, chemical precipitation, filtration, and sludge dewatering are commercially available technologies for the treatment of F007-F009, F011, and similar wastes and thus are "available" to be used in treatment of cyanide-containing wastes prior to generation of F006, F012, F019, and similar wastes.

Also, as shown in Table 4-1, the treatment train discussed above substantially reduces the concentration of cyanide in F012 waste compared to the waste from which it was generated. Stabilization treatment of the treatment sludges generated by chemical precipitation has been shown previously, in the case of F006, to result in substantial reductions in leachate concentrations of BDAT list metals. Therefore, the treatment train discussed above, followed by stabilization of the F006, F012, F019, or similar waste thus generated, is "available" and thus is BDAT for F006, F012, and F019 and is the basis for cyanide standards for wastewater treatment sludge residuals from the treatment of F007, F008, F009, and F011 wastes.

Alternatively, the Agency believes that the cyanide treatment standards for this subcategory can be achieved by treatment of wastewaters by well-designed and well-operated alkaline chlorination treatment alone. As stated previously, the Agency believes that wastes with high influent concentrations of cyanide can be treated by alkaline chlorination to achieve similar treatment performance.

5.3 BDAT for the Metal Finishing Organic Liquids Subcategory

The data available to the Agency on incineration of F010 waste (presented in Table 4-6) indicate that incineration achieves a substantial reduction in cyanide concentration in the incinerator ash compared to the untreated waste. Accuracy adjustment of these data is detailed in Table 5-4. No data were submitted on BDAT metals in the untreated waste or the ash residual. The Agency has no information as to which, if any, metals are present in F010 waste or the ash residual from incineration of this waste. The Agency is soliciting comments from industry on the presence of metals or other organics in F010 wastes.

No data are available on the composition of the scrubber water from incineration of F010, but the Agency expects this scrubber water to be less difficult to treat than the other wastewaters regulated (F007 and

F009 wastewaters) because the concentrations of cyanide and BDAT list metals would be lower. Therefore, the best demonstrated technology for these scrubber waters is wet air oxidation.

Incineration and wet air oxidation are both commercially available technologies and thus are "available" for the purposes of establishing BDAT. Therefore, BDAT for the metal finishing organic liquids subcategory is incineration followed by wet air oxidation treatment of the scrubber waters.

Table 5-1 Summary of Accuracy Adjustment of Treatment Data for Amenable Cyanide in Wastewaters

	Untreated waste concentration (mg/l)	Measured treated waste concentration (mg/l)	Percent recovery for matrix spike test	Accuracy correction factor	Accuracy-adjusted concentration (mg/l)
Wet Air Oxidation					
Sample Set No. 2	CBI	<0.25	52	1.923	<0.48
Sample Set No. 3	CBI	<0.25	52	1.923	<0.48
Sample Set No. 4	CBI	<0.25	52	1.923	<0.48
Sample Set No. 5	CBI	<0.25	52	1.923	<0.48
Sample Set No. 6	CBI	<0.25	52	1.923	<0.48
Electrolytic Oxidation/Alkaline Chlorination					
Sample Set No. 1	I[a]	-	-	-	3.0

- = Not available. Quantities actually measured were total cyanide and "chlorinated cyanide," which were both adjusted for accuracy. The accuracy-adjusted value for chlorinated cyanide was then subtracted from the accuracy-adjusted value for total cyanide to obtain the accuracy-adjusted concentration of amenable cyanide. (See Appendix B for detailed calculations.)

[a] Value for total cyanide concentration was 5350.

Table 5-2 Summary of Accuracy Adjustment of Treatment Data for Total Cyanide in Wastewaters

	Untreated waste concentration (mg/l)	Measured treated waste concentration (mg/l)	Percent recovery for matrix spike test	Accuracy correction factor	Accuracy-adjusted concentration (mg/l)
Wet Air Oxidation					
Sample Set No. 2	CBI	<0.25	52	1.923	<0.48
Sample Set No. 3	CBI	3.22	52	1.923	6.19
Sample Set No. 4	CBI	<0.25	52	1.923	<0.48
Sample Set No. 5	CBI	<0.25	52	1.923	<0.48
Sample Set No. 6	CBI	<0.25	52	1.923	<0.48
Electrolytic Oxidation/Alkaline Chlorination					
Sample Set No. 1	5,350	103	88	1.136	117

Table 5-3 Summary of Accuracy Adjustment of Cyanide Data in F012 Waste as Generated

	Untreated waste concentration (mg/l)	Percent recovery for matrix spike test	Accuracy correction factor	Accuracy-adjusted concentration (mg/l)
Sample Set No. 1				
Cyanide (amenable)	-	-	-	<0.023
Cyanide (total)	99.4	102	0.98	97.4
Sample Set No. 2				
Cyanide (amenable)	-	-	-	<0.023
Cyanide (total)	34.7	93	1.08	37.3

- = Not available. Quantities actually measured were total cyanide and "chlorinated cyanide," which were both adjusted for accuracy. The accuracy-adjusted value for chlorinated cyanide was then subtracted from the accuracy-adjusted value for total cyanide to obtain the accuracy-adjusted concentration of amenable cyanide. (See Appendix B for detailed calculations.)

Table 5-4 Summary of Accuracy Adjustment of Treatment Data for Total Cyanide in F010 Waste

	Untreated waste concentration (mg/kg)	Measured treated waste concentration (mg/kg)	Percent recovery for matrix spike test	Accuracy correction factor	Accuracy-adjusted concentration (mg/kg)
Sample Set No. 1					
Cyanide (total)	22,000	0.45	96	1.04	0.468
Sample Set No. 2					
Cyanide (total)	20,000	0.40	96	1.04	0.416
Sample Set No. 3					
Cyanide (total)	-	0.88	96	1.04	0.915

- = Not available. Only two untreated waste samples were collected.

6. SELECTION OF REGULATED CONSTITUENTS

This section presents the rationale for selection of the proposed regulated constituents for the treatment of F006-F012 and F019 wastes.

Constituents selected for regulation must satisfy the following criteria:

1. They must be on the BDAT list of regulated constituents or must be indicators for other BDAT list constituents. (Presence on the BDAT list implies the existence of approved techniques for analyzing the constituent in treated wastes.)
2. They must be present in, or suspected of being present in, the untreated waste. For example, in some cases, analytical difficulties (such as masking) may prevent a constituent from being identified in the untreated waste, but its identification in a treatment residual may lead the Agency to conclude that it is present in the untreated waste.
3. Where performance data are transferred, the selected constituents must be easier to treat than the waste constituent(s) from which performance data are transferred. Factors for assessing ease of treatment will vary according to the technology of concern. For instance, for incineration the factors include bond dissociation energy, thermal conductivity, and boiling point.

From the group of constituents that are eligible to be regulated, EPA may select a subset of constituents as representative of the broader group. For instance, out of a group of constituents that react similarly to treatment, the Agency might name only those found in the highest concentrations or those that are the most difficult to treat as regulated constituents for the purpose of setting a standard.

6.1 Identification of BDAT List Constituents

Table 6-1 shows which BDAT list constituents were analyzed for in all wastes tested by EPA (F007, F011, F012), which constituents were detected, and which constituents the Agency believes may be present even though not detected in the untreated waste on which treatment tests were performed. BDAT list metals and cyanide were detected in all of the wastes sampled.

For the F007 waste tested, one volatile organic compound was detected, methanol. One PCB compound, Aroclor 1254, was detected at a concentration slightly above the detection limit, and several volatile and semivolatile organic compounds were detected in the F012 waste tested. No other BDAT list organic compounds were detected, or are believed to be commonly present, in any of the wastes tested or any of the wastes regulated by this document based on the Agency's knowledge of the electroplating and heat treating processes. The detection of a PCB compound in the F012 waste tested is probably attributable to a cleanup of PCB transformers that had recently occurred at the plant where this waste was collected. The organic compounds detected in F012 (bis(2-ethylhexyl) phthalate, acetone, chloroform, methylene chloride, and toluene) were probably contaminants of the rinsewaters treated along with the quenching wastewaters. These organic compounds were all found at very low concentrations and are not believed to be treatable at these concentrations. The methanol detected in the F007 waste tested was probably a constituent of the electroplating bath, but is not commonly used in such an application; thus, it is not proposed for regulation.

6.2 Determination of Regulated Constituents

For the metal finishing aqueous liquids subcategory, EPA is proposing to regulate total and amenable cyanide in both wastewater and nonwastewater treatment residuals based on the performance of wet air oxidation. The Agency is also proposing to regulate chromium, lead, and nickel in wastewaters and cadmium, chromium, lead, nickel, and silver in nonwastewaters. Regulated constituent selection for nonwastewaters and wastewaters is based on treatment of the effluent from wet air oxidation by chemical precipitation followed by filtration for the wastewaters and subsequent dewatering followed by stabilization of the nonwastewater residual. All of the metals listed above are commonly found in electroplating and heat treating wastes. Amenable and total cyanides are proposed for regulation based on the total waste composition analysis. EPA feels that because these standards are based on a destruction technology, the appropriate measure of performance is total waste composition. Also, because there may be a difference in performance of cyanide destruction technologies between complexed and noncomplexed cyanide, both amenable and total cyanide standards are proposed. The Agency has no data on the treatment of wastewaters for cadmium and silver by chemical precipitation, but believes that these constituents will be controlled by treatment of the other metals proposed for regulation.

The only other metals that are commonly detected in these wastes at high concentrations, according to the waste characterization data presented in Section 2, are copper and zinc. EPA is not regulating copper and zinc for the wastes in this subcategory because these constituents are not listed in Appendix VIII of 40 CFR Part 261 as elemental constituents but rather as specific compounds (i.e., copper cyanide, zinc phosphide, and zinc cyanide). In any case, treatment of the other BDAT list metals by chemical precipitation and/or stabilization will also reduce leachate concentrations of both of these metals in wastewater and nonwastewater treatment residuals.

For the metal finishing treatment sludges subcategory (F006, F012, and F019), EPA is proposing to regulate amenable and total cyanide in both wastewaters and nonwastewaters. For F012 and F019 wastewaters, the Agency is proposing to regulate chromium, lead, and nickel. For F012 and F019 nonwastewaters, the Agency is proposing to regulate cadmium, chromium, lead, nickel, and silver. These metals have been previously regulated for F006 nonwastewaters (see EPA's BDAT Background Document for F006).

For the metal finishing organic liquids (F010), EPA is proposing to regulate total cyanide in the total composition analysis for both wastewater and nonwastewater residuals. For incineration, the Agency believes that total cyanide is the appropriate measure of performance, as it has no evidence that complexed cyanides are any more difficult to treat by thermal treatment methods such as incineration than are free cyanides. As discussed in Section 5.3, EPA has no data on metals in this waste.

Table 6-1 Status of BDAT List Constituent Presence in Untreated Tested Wastes

BDAT reference no.	Constituent	F007	F011	F012
	Volatile Organics			
222.	Acetone	ND	ND	D
1.	Acetonitrile	ND	ND	ND
2.	Acrolein	ND	ND	ND
3.	Acrylonitrile	ND	ND	ND
4.	Benzene	ND	ND	ND
5.	Bromodichloromethane	ND	ND	ND
6.	Bromomethane	ND	ND	ND
223.	n-Butyl alcohol	ND	NA	NA
7.	Carbon tetrachloride	ND	ND	ND
8.	Carbon disulfide	ND	ND	ND
9.	Chlorobenzene	ND	ND	ND
10.	2-Chloro-1,3-butadiene	ND	ND	ND
11.	Chlorodibromomethane	ND	ND	ND
12.	Chloroethane	ND	ND	ND
13.	2-Chloroethyl vinyl ether	ND	ND	ND
14.	Chloroform	ND	ND	D
15.	Chloromethane	ND	ND	ND
16.	3-Chloropropene	ND	ND	ND
17.	1,2-Dibromo-3-chloropropane	ND	ND	ND
18.	1,2-Dibromoethane	ND	ND	ND
19.	Dibromomethane	ND	ND	ND
20.	trans-1,4-Dichloro-2-butene	ND	ND	ND
21.	Dichlorodifluoromethane	ND	ND	ND
22.	1,1-Dichloroethane	ND	ND	ND
23.	1,2-Dichloroethane	ND	ND	ND
24.	1,1-Dichloroethylene	ND	ND	ND
25.	trans-1,2-Dichloroethene	ND	ND	ND
26.	1,2-Dichloropropane	ND	ND	ND
27.	trans-1,3-Dichloropropene	ND	ND	ND
28.	cis-1,3-Dichloropropene	ND	ND	ND
29.	1,4-Dioxane	ND	ND	ND
224.	2-Ethoxyethanol	ND	NA	NA
225.	Ethyl acetate	ND	NA	NA
226.	Ethyl benzene	ND	ND	ND
30.	Ethyl cyanide	ND	ND	ND
227.	Ethyl ether	ND	NA	NA
31.	Ethyl methacrylate	ND	ND	ND
214.	Ethylene oxide	ND	ND	ND
32.	Iodomethane	ND	ND	ND
33.	Isobutyl alcohol	ND	ND	ND
228.	Methanol	D	NA	NA
34.	Methyl ethyl ketone	ND	ND	ND

Table 6-1 (continued)

BDAT reference no.	Constituent	F007	F011	F012
	Volatile Organics (continued)			
229.	Methyl isobutyl ketone	ND	ND	ND
35.	Methyl methacrylate	ND	ND	ND
37.	Methacrylonitrile	ND	ND	ND
38.	Methylene chloride	ND	ND	D
230.	2-Nitropropane	ND	NA	NA
39.	Pyridine	ND	ND	ND
40.	1,1,1,2-Tetrachloroethane	ND	ND	ND
41.	1,1,2,2-Tetrachloroethane	ND	ND	ND
42.	Tetrachloroethene	ND	ND	ND
43.	Toluene	ND	ND	D
44.	Tribromomethane	ND	ND	ND
45.	1,1,1-Trichloroethane	ND	ND	ND
46.	1,1,2-Trichloroethane	ND	ND	ND
47.	Trichloroethene	ND	ND	ND
48.	Trichloromonofluoromethane	ND	ND	ND
49.	1,2,3-Trichloropropane	ND	ND	ND
231.	1,1,2-Trichloro-1,2,2-trifluoroethane	NA	NA	NA
50.	Vinyl chloride	ND	ND	ND
215.	1,2-Xylene	ND	ND	ND
216.	1,3-Xylene	ND	ND	ND
217.	1,4-Xylene	ND	ND	ND
	Semivolatile Organics			
51.	Acenaphthylene	ND	ND	ND
52.	Acenaphthene	ND	ND	ND
53.	Acetophenone	ND	ND	ND
54.	2-Acetylaminofluorene	ND	ND	ND
55.	4-Aminobiphenyl	ND	ND	ND
56.	Aniline	ND	ND	ND
57.	Anthracene	ND	ND	ND
58.	Aramite	NA	ND	ND
59.	Benz(a)anthracene	ND	ND	ND
218.	Benzal chloride	ND	NA	NA
60.	Benzenethiol	NA	ND	ND
61.	Deleted			
62.	Benzo(a)pyrene	ND	ND	ND
63.	Benzo(b)fluoranthene	ND	ND	ND
64.	Benzo(ghi)perylene	ND	ND	ND
65.	Benzo(k)fluoranhene	ND	ND	ND
66.	p-Benzoquinone	NA	ND	ND

Table 6-1 (continued)

BDAT reference no.	Constituent	F007	F011	F012
	Semivolatile Organics (continued)			
67.	Bis(2-chloroethoxy)methane	ND	ND	ND
68.	Bis(2-chloroethyl) ether	ND	ND	ND
69.	Bis(2-chloroisopropyl) ether	ND	ND	ND
70.	Bis(2-ethylhexyl) phthalate	ND	ND	D
71.	4-Bromophenyl phenyl ether	ND	ND	ND
72.	Butylbenzyl phthalate	ND	ND	ND
73.	2-sec-Butyl-4,6-dinitrophenol	ND	ND	ND
74.	p-Chloroaniline	ND	ND	ND
75.	Chlorobenzilate	ND	ND	ND
76.	p-Chloro-m-cresol	ND	ND	ND
77.	2-Chloronaphthalene	ND	ND	ND
78.	2-Chlorophenol	ND	ND	ND
79.	3-Chloropropionitrile	ND	ND	ND
80.	Chrysene	ND	ND	ND
81.	ortho-Cresol	ND	ND	ND
82.	para-Cresol	ND	ND	ND
232.	Cyclohexanone	ND	NA	NA
83.	Dibenz(a,h)anthracene	ND	ND	ND
84.	Dibenzo(a,e)pyrene	NA	ND	ND
85.	Dibenzo(a,i)pyrene	NA	ND	ND
86.	m-Dichlorobenzene	ND	ND	ND
87.	o-Dichlorobenzene	ND	ND	ND
88.	p-Dichlorobenzene	ND	ND	ND
89.	3,3'-Dichlorobenzidine	ND	ND	ND
90.	2,4-Dichlorophenol	ND	ND	ND
91.	2,6-Dichlorophenol	ND	ND	ND
92.	Diethyl phthalate	ND	ND	ND
93.	3,3'-Dimethoxybenzidine	ND	ND	ND
94.	p-Dimethylaminoazobenzene	ND	ND	ND
95.	3,3'-Dimethylbenzidine	ND	ND	ND
96.	2,4-Dimethylphenol	ND	ND	ND
97.	Dimethyl phthalate	ND	ND	ND
98.	Di-n-butyl phthalate	ND	ND	ND
99.	1,4-Dinitrobenzene	ND	ND	ND
100.	4,6-Dinitro-o-cresol	ND	ND	ND
101.	2,4-Dinitrophenol	ND	ND	ND
102.	2,4-Dinitrotoluene	ND	ND	ND
103.	2,6-Dinitrotoluene	ND	ND	ND
104.	Di-n-octyl phthalate	ND	ND	ND
105.	Di-n-propylnitrosamine	ND	ND	ND
106.	Diphenylamine	ND	ND	ND
219.	Diphenylnitrosamine	ND	ND	ND

Table 6-1 (continued)

BDAT reference no.	Constituent	F007	F011	F012
	Semivolatile Organics (continued)			
107.	1,2-Diphenylhydrazine	ND	ND	ND
108.	Fluoranthene	ND	ND	ND
109.	Fluorene	ND	ND	ND
110.	Hexachlorobenzene	ND	ND	ND
111.	Hexachlorobutadiene	ND	ND	ND
112.	Hexachlorocyclopentadiene	ND	ND	ND
113.	Hexachloroethane	ND	ND	ND
114.	Hexachlorophene	NA	ND	ND
115.	Hexachloropropene	ND	ND	ND
116.	Indeno(1,2,3-cd)pyrene	ND	ND	ND
117.	Isosafrole	ND	ND	ND
118.	Methapyrilene	ND	ND	ND
119.	3-Methylcholanthrene	NA	ND	ND
120.	4,4'-Methylenebis-(2-chloroaniline)	ND	ND	ND
36.	Methyl methanesulfonate	ND	ND	ND
121.	Naphthalene	ND	ND	ND
122.	1,4-Naphthoquinone	ND	ND	ND
123.	1-Naphthylamine	NA	ND	ND
124.	2-Naphthylamine	ND	ND	ND
125.	p-Nitroaniline	ND	ND	ND
126.	Nitrobenzene	ND	ND	ND
127.	4-Nitrophenol	ND	ND	ND
128.	N-Nitrosodi-n-butylamine	ND	ND	ND
129.	N-Nitrosodiethylamine	ND	ND	ND
130.	N-Nitrosodimethylamine	ND	ND	ND
131.	N-Nitrosomethylethylamine	ND	ND	ND
132.	N-Nitrosomorpholine	ND	ND	ND
133.	N-Nitrosopiperidine	ND	ND	ND
134.	N-Nitrosopyrrolidine	ND	ND	ND
135.	5-Nitro-o-toluidine	ND	ND	ND
136.	Pentachlorobenzene	ND	ND	ND
137.	Pentachloroethane	NA	ND	ND
138.	Pentachloronitrobenzene	ND	ND	ND
139.	Pentachlorophenol	ND	ND	ND
140.	Phenacetin	ND	ND	ND
141.	Phenanthrene	ND	ND	ND
142.	Phenol	ND	ND	ND
220.	Phthalic anhydride	ND	NA	NA
143.	2-Picoline	ND	ND	ND
144.	Pronamide	ND	ND	ND
145.	Pyrene	ND	ND	ND
146.	Resorcinol	NA	ND	ND

Table 6-1 (continued)

BDAT reference no.	Constituent	F007	F011	F012
	Semivolatile Organics (continued)			
147.	Safrole	ND	ND	ND
148.	1,2,4,5-Tetrachlorobenzene	ND	ND	ND
149.	2,3,4,6-Tetrachlorophenol	ND	ND	ND
150.	1,2,4-Trichlorobenzene	ND	ND	ND
151.	2,4,5-Trichlorophenol	ND	ND	ND
152.	2,4,6-Trichlorophenol	ND	ND	ND
153.	Tris(2,3-dibromopropyl) phosphate	ND	ND	ND
	Metals			
154.	Antimony	ND	D	ND
155.	Arsenic	ND	ND	ND
156.	Barium	ND	D	D
157.	Beryllium	ND	ND	ND
158.	Cadmium	ND-X	D	D
159.	Chromium (total)	D	D	D
221.	Chromium (hexavalent)	I-Y	ND	I
160.	Copper	D	D	D
161.	Lead	ND	D	D
162.	Mercury	D	ND	ND
163.	Nickel	ND-X	D	D
164.	Selenium	ND	ND	ND
165.	Silver	ND-X	D	D
166.	Thallium	ND	ND	ND
167.	Vanadium	ND	D	D
168.	Zinc	D	D	D
	Inorganics Other Than Metals			
169.	Cyanide	D	D	D
170.	Fluoride	D	D	D
171.	Sulfide	NA	ND	ND
	Organochlorine Pesticides			
172.	Aldrin	ND	NA	NA
173.	alpha-BHC	ND	NA	NA
174.	beta-BHC	ND	NA	NA
175.	delta-BHC	ND	NA	NA

Table 6-1. (continued)

BDAT reference no.	Constituent	F007	F011	F012
	Organochlorine Pesticides (continued)			
176.	gamma-BHC	ND	NA	NA
177.	Chlordane	ND	NA	NA
178.	DDD	ND	NA	NA
179.	DDE	ND	NA	NA
180.	DDT	ND	NA	NA
181.	Dieldrin	ND	NA	NA
182.	Endosulfan I	ND	NA	NA
183.	Endosulfan II	ND	NA	NA
184.	Endrin	ND	NA	NA
185.	Endrin aldehyde	ND	NA	NA
186.	Heptachlor	ND	NA	NA
187.	Heptachlor epoxide	ND	NA	NA
188.	Isodrin	ND	NA	NA
189.	Kepone	ND	NA	NA
190.	Methoxyclor	ND	NA	NA
191.	Toxaphene	ND	NA	NA
	Phenoxyacetic Acid Herbicides			
192.	2,4-Dichlorophenoxyacetic acid	ND	NA	NA
193.	Silvex	ND	NA	NA
194.	2,4,5-T	ND	NA	NA
	Organophosphorous Insecticides			
195.	Disulfoton	ND	NA	NA
196.	Famphur	ND	NA	NA
197.	Methyl parathion	ND	NA	NA
198.	Parathion	ND	NA	NA
199.	Phorate	ND	NA	NA
	PCBs			
200.	Aroclor 1016	ND	ND	ND
201.	Aroclor 1221	ND	ND	ND
202.	Aroclor 1232	ND	ND	ND
203.	Aroclor 1242	ND	ND	ND
204.	Aroclor 1248	ND	ND	ND
205.	Aroclor 1254	ND	ND	D
206.	Aroclor 1260	ND	ND	ND

Table 6-1 (continued)

BDAT reference no.	Constituent	F007	F011	F012
	Dioxins and Furans			
207.	Hexachlorodibenzo-p-dioxins	ND	ND	ND
208.	Hexachlorodibenzofurans	ND	ND	ND
209.	Pentachlorodibenzo-p-dioxins	ND	ND	ND
210.	Pentachlorodibenzofurans	ND	ND	ND
211.	Tetrachlorodibenzo-p-dioxins	ND	ND	ND
212.	Tetrachlorodibenzofurans	ND	ND	ND
213.	2,3,7,8-Tetrachlorodibenzo-p-dioxin	NA	ND	ND

D = Detected
ND = Not detected.
NA = Not analyzed.
I = Analytical interference (matrix effects) prevented analysis.
X = Believed to be present based on engineering analysis of waste generating process.
Y = Believed to be present based on detection in treated residuals.

References: USEPA 1988e, 1988f.

7. CALCULATION OF PROPOSED BDAT TREATMENT STANDARDS

This section presents the calculation of the proposed treatment standards using analytical treatment data for the regulated constituents selected in Section 6. The Agency bases treatment standards for regulated constituents on the performance of well-designed and well-operated BDAT treatment systems. These standards must account for analytical limitations in available performance data and must be adjusted for variabilities related to treatment, sampling, and analytical techniques and procedures.

BDAT standards are determined for each constituent by multiplying the arithmetic mean of accuracy-adjusted constituent concentrations detected in treated waste by a "variability factor" specific to each constituent for each treatment technology defined as BDAT. Accuracy adjustment of performance data has been discussed in Section 5 in relation to defining "substantial treatment." Variability factors correct for normal variations in the performance of a particular technology over time. They are designed to reflect the 99th percentile level of performance that the technology achieves in commercial operation. (For more information on the principles of calculating variability factors, see EPA's publication, Methodology for Developing BDAT Treatment Standards (USEPA 1988d).) Details on the calculation of variability factors for F006-F012 and F019 wastes are presented in this section.

Where EPA has identified BDAT for a particular waste, but because of data limitations or for some other compelling reason cannot define specific treatment standards for that waste, the Agency can require the use of that treatment process as a technology standard. Similarly, where there are no known generators of a waste, or where EPA believes that the waste can be totally recycled or reused as a raw material, the Agency may specify a "no land disposal as generated" standard, which effectively amounts to setting the performance standard at zero for all waste constituents.

7.1 Cyanide

EPA is proposing both nonwastewater and wastewater treatment standards for amenable and total cyanide for each of the three waste subcategories established in Section 2.4. These subcategories are as follows: (1) metal finishing aqueous liquids subcategory (F007, F008, F009, and F011; (2) metal finishing sludges subcategory (F006, F012, and F019); and (3) metal finishing organic liquids subcategory (F010). Proposed cyanide standards for wastewaters for all three subcategories are based on performance data from wet air oxidation of F007 waste. Proposed nonwastewater treatment standards for the second subcategory, as generated, are based on analysis of F012 waste generated as a residual from treatment of F011 waste and heat treating quenching wastewaters by electrolytic oxidation followed by alkaline chlorination, chemical precipitation, filtration, and sludge dewatering. These proposed nonwastewater standards are also transferred to nonwastewater residuals generated by treatment of wastes in the first subcategory. Proposed nonwastewater standards for the third subcategory are based on data from treatment of F010 and a similar waste by incineration.

In addition, the Agency believes that other applicable technologies that destroy amenable and complexed cyanides can achieve similar treatment performance levels as long as the treatment systems are well designed and well operated.

7.2 BDAT List Metals

EPA is proposing nonwastewater treatment standards for BDAT list metals for F007-F009, F011, F012, and F019 based on the treatment standards established for treatment of F006 by stabilization. (See EPA's Best Demonstrated Available Technology (BDAT) Background Document for F006 (USEPA 1988a).) Wastewater treatment standards for these wastes are also being established by the Agency based on transfer of the treatment standards established for treatment of K062 waste by chemical precipitation followed by filtration. (See EPA's Best Demonstrated Availability Technology (BDAT) Background Document for K062 (USEPA 1988b).)

Table 7-1 Calculation of Proposed Treatment Standards for Total and Amenable Cyanide for Waste Codes F007, F008, F009, and F011 Based on Wet Air Oxidation

Regulated constituent (units)	Accuracy-adjusted treated waste concentration[a]	Mean treated waste concentration	Variability factor (VF)	Treatment standard (total composition)
Wastewater (mg/l):				
Cyanide (amenable)	<0.48 <0.48 <0.48 <0.48 <0.48	0.48	2.8	1.3
Cyanide (total)	<0.48 6.19 <0.48 <0.48 <0.48	1.62	7.09	12

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[a] See Tables 5-1 and 5-2.

Table 7-2 Calculation of Proposed Treatment Standards for Total and Amenable Cyanide for Waste Codes F006, F012, and F019 Based on Generation of F012 Waste by a Well-Operated Treatment Process Consisting of Electrolytic Oxidation, Alkaline Chlorination, Chemical Precipitation, Filtration, and Sludge Dewatering

Regulated constituent (units)	Accuracy-adjusted treated waste concentration[a]	Mean treated waste concentration	Variability factor (VF)	Treatment standard (total composition)
Nonwastewater (mg/kg):				
Cyanide (amenable)	<0.023 <0.023	0.023	2.8	0.064
Cyanide (total)	97.4 37.3	67.35	1.58	110

[a] See Table 5-3.

Table 7-3 Calculation of Proposed Treatment Standards for Incineration of F010

Regulated constituent (units)	Accuracy-adjusted treated waste concentration[a]	Mean treated waste concentration	Variability factor (VF)	Treatment standard (total composition)
Nonwastewater (mg/kg):				
Cyanide (total)	0.468 0.416 0.915	0.60	2.53	1.5

[a] See Table 5-4.

Table 7-4 Proposed BDAT Treatment Standards for F007, F008, F009, and F011

Constituent	Wastewater	Nonwastewater	
	Total composition (mg/l)	Total composition (mg/kg)	TCLP (mg/l)
Cyanide (amenable)	1.3	0.064	NA
Cyanide (total)	12	110	NA
Cadmium	-	NA	0.066
Chromium	0.32	NA	5.2
Lead	0.04	NA	0.51
Nickel	0.44	NA	0.32
Silver	-	NA	0.072

NA = Not applicable.
- = No treatment standard.

Table 7-5 Proposed BDAT Treatment Standards for F006 (Cyanide)

Constituent	Nonwastewater	
	Total composition (mg/kg)	TCLP (mg/l)
Cyanide (amenable)	0.064	NA
Cyanide (total)	110	NA

NA = Not applicable.

Table 7-6 Proposed BDAT Treatment Standards for F012 and F019

Constituent	Wastewater	Nonwastewater	
	Total composition (mg/l)	Total composition (mg/kg)	TCLP (mg/l)
Cyanide (amenable)	1.3	0.064	NA
Cyanide (total)	12	110	NA
Cadmium	-	NA	0.066
Chromium	0.32	NA	5.2
Lead	0.04	NA	0.51
Nickel	0.44	NA	0.32
Silver	-	NA	0.072

NA = Not applicable.

- = No treatment standard.

Table 7-7 Proposed BDAT Treatment Standards for F010

Constituent	Wastewater	Nonwastewater	
	Total composition (mg/l)	Total composition (mg/kg)	TCLP (mg/l)
Cyanide (amenable)	1.3	-	NA
Cyanide (total)	12	1.5	NA

NA = Not applicable.
- = No treatment standard.

8. P WASTE CODES

This section addresses regulation of those P wastes that are similar to the metal finishing cyanide wastes. These wastes, listed in Table 8-1, are identified in 40 CFR 261.33 as "discarded commercial chemical products, off-specification species, container residues, and spill residues thereof."

8.1 Industries Affected

Industries that may generate these wastes are the manufacturers of cyanide compounds listed in Table 8-1 as well as electroplaters, heat treaters, and other industries that use inorganic cyanide salts. In addition, hydrogen cyanide is a chemical intermediate used in the production of acetone cyanohydrin, adiponitrile, cyanuric chloride, methyl methacrylate, methionine, sodium cyanide, and other chemicals. Thus, P063 wastes may be generated by producers of these chemicals.

8.2 Applicable and Demonstrated Treatment Technologies

The compounds listed in Table 8-1 are soluble in water to form waste solutions that are similar in nature to the F007 and F011 wastes tested by the Agency and other wastes composing the metal finishing aqueous liquids subcategory as identified in Section 2.4. Therefore, the Agency believes electrolytic oxidation, alkaline chlorination, wet air oxidation, high-temperature cyanide hydrolysis, and SO_2/air oxidation are applicable and demonstrated to treat off-specification product, wastewater, and contaminated soil and sludge forms of the P codes listed.

Metals can be treated by chemical precipitation followed by filtration, sludge dewatering, and stabilization for wastewaters, and by stabilization for nonwastewaters.

8.3 Identification of Best Demonstrated Available Technology

Of the demonstrated technologies identified in Section 8.2, the "best" technology for cyanide treatment for these wastes is wet air oxidation. For treatment of BDAT metal constituents, the "best" technology is chemical precipitation followed by filtration and sludge dewatering. Cyanide standards for wastewater treatment sludge residuals are based on generation of these sludges by electrolytic oxidation followed by alkaline chlorination, chemical precipitation, and sludge dewatering. Determination of "best" technology and "availability" for both cyanides and metals follows the rationale that was presented in Section 5.1 for the metal finishing aqueous liquids subcategory and in Section 5.2 for the metal finishing sludges subcategory (for the treatment sludges).

8.4 Selection of Regulated Constituents

EPA is proposing to regulate total and amenable cyanide in both wastewaters and nonwastewaters for all of the P-code wastes listed in Table 8-1. The BDAT list metals proposed for regulation, also listed in Table 8-1, are copper for P029, nickel for P074, silver for P099 and P104, and zinc for P121. The silver and zinc standards for wastewaters are reserved because the Agency has not completed its evaluation of data on the performance of chemical precipitation and filtration treatment for these metals.

The Agency has proposed copper and zinc as regulated constituents only for the copper cyanide (P029) and zinc cyanide (P121) wastes. In the preamble to the final rule for Land Disposal Restrictions for First Third Scheduled Wastes (53 FR 31152, August 17, 1988), the Agency did not regulate copper and zinc, in part because these metal constituents were controlled by treatment of the metal constituents that were regulated. For the P029 and P121 waste codes, copper and zinc, as the primary metal constituents, may be present in very high concentrations (up to 55 percent in the pure compound wastes).

The Agency believes that treatment for copper and zinc removal is necessary for such wastes. EPA has determined that these wastes are aquatic toxins, and considered adding them to Appendix VIII for that reason. Furthermore, treatment performance for copper and zinc for these wastes is an indicator of the performance of treatment of any other BDAT list metals that might be present in the wastes.

8.5 Proposed Treatment Standards

All wastewater and nonwastewater residuals from treatment of these wastes must meet the wastewater and nonwastewater standards presented in Table 8-2 for the constituents listed in Table 8-1.

Table 8-1 P Waste Codes Proposed for Regulation

Waste code	Chemical compound	Regulated constituents
P013	Barium cyanide	Cyanide
P021	Calcium cyanide	Cyanide
P029	Copper cyanide	Copper, cyanide
P030	Cyanides (soluble cyanide salts), N.O.S.	Cyanide
P063	Hydrocyanic acid, hydrogen cyanide	Cyanide
P074	Nickel cyanide	Nickel, cyanide
P098	Postassium cyanide	Cyanide
P099	Postassium silver cyanide	Silver, cyanide
P104	Silver cyanide	Silver, cyanide
P106	Sodium cyanide	Cyanide
P121	Zinc cyanide	Zinc, cyanide

Table 8-2 Proposed Treatment Standards for P-code Cyanide Wastes

Constituent	Wastewater	Nonwastewater (treatment sludge)	
	Total composition (mg/l)	Total composition (mg/kg)	TCLP (mg/l)
Cyanide (amenable)	1.3	0.064	NA
Cyanide (total)	12	110	NA
Copper (P029 only)	0.42	NA	0.71
Nickel (P074 only)	0.44	NA	0.30
Silver (P099 and P104 only)	reserved	NA	0.07
Zinc (P121 only)	reserved	NA	0.086

NA = Not applicable.

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APPENDIX A

ANALYTICAL METHODS AND QA/QC

This appendix presents analytical methods and the matrix spike recovery data for the treated waste samples from testing of F007, F011, and F012 wastes.

Table A-1 Analytical Methods - Plant A

Analytical method	Method number	Reference
Cyanides (total and amenable)	9012	1

1. USEPA. 1986. U.S. Environmental Protection Agency, Office of Solid Waste. Test methods for evaluating solid waste. 3rd ed. Washington, D.C.: U.S. Environmental Protection Agency.

Table A-2 Specific Procedures or Equipment Used for Analysis of Cyanide When Alternatives or Equivalents Are Allowed in SW-846 Methods - Plant A

Analysis	SW-846 method	Sample aliquot	Alternative or equivalent allowed by SW-846 methods	Specific procedure used
Total and amenable cyanide	9012	500 ml	Hydrogen sulfide treatment may be required.	Hydrogen sulfide treatment was not required.
			A Fisher-Mulligan absorber or equivalent should be used.	A Wheaton Distilling Apparatus absorber was used.

Table A-3 Matrix Spike Recoveries for Cyanide - Plant A

Constituent	Original amount detected (µg/l)	Amount spiked (µg/l)	Spike		Duplicate spike		Relative percent difference[b]
			Amount recovered (µg/l)	Percent recovery[a]	Amount recovered (µg/l)	Percent recovery[a]	
Sample WGS4-101							
Cyanide, chlorinated	114,000	160,000	279,000	103	274,000	100	1.8
Cyanide, total	103,000	160,000	243,000	88	252,000	93	3.6
Sample WGS8-101							
Cyanide, chlorinated	<10	200	140	70	120	60	15
Cyanide, total	<10	200	<10	0.0[c]	<10	0.0[c]	NC
Sample WGS5-10							
Cyanide, chlorinated[d]	79.5	71.1	110	43	-	-	-
Cyanide, total[d]	99.4	69.3	170	102	173[e]	108	1.0
Cyanide, TCLP	854	1000	1820	97	1990	114	8.9
Sample WGS9-101							
Cyanide, chlorinated[d]	29.1	30.7	59.5	77	-	-	-
Cyanide, total[d]	34.7	7.99	42.1	93	44.0[f]	116	23
Cyanide, TCLP	40.8	200	225	92	222	91	1.3

NC = Not calculable.

- = No analysis performed.

[a] Percent recovery = 100 $(C_1 - C_o) / C_t$, where C_1 is the amount recovered, C_o is the original amount detected.

[b] Relative percent difference = $| 100 (D_1 - D_2) / [(D_1 + D_2) / 2] |$, where D_1 and D_2 are the percent recoveries of the spike and duplicate spike.

[c] Zero percent recovery is attributed to matrix interference.

[d] Units for solids sample concentrations are mg/kg.

[e] Amount spiked for the matrix duplicate spike was 68.1 mg/kg.

[f] Amount spiked for matrix spike duplicate was 7.96 mg/kg.

Table A-4 Analytical Methods - Plant B

Analytical method	Method number	Reference
Cyanides (total and amenable)	9010	1

1. USEPA. 1986. U.S. Environmental Protection Agency, Office of Solid Waste. Test method for evaluating solid waste. 3rd ed. Washington, D.C.: U.S. Environmental Protection Agency.

Table A-5 Specific Procedures or Equipment Used for Analysis of Cyanide When Alternatives or Equivalents Are Allowed in SW-846 Methods - Plant B

Analysis	Method	Alternative or equivalent allowed	Specific equipment or procedure used
Cyanide	9010	Pretreatment with bismuth nitrate may be necessary if sulfides are present.	Pretreatment was not necessary.
		Pretreatment with sulfamic acid may be necessary if nitrites/nitrates are present.	Pretreatment was not necessary.
		A Fisher-Mulligan absorber or equivalent should be used.	An ACE smog bubbler absorber was used.
		A spectrophotometer suitable for measurements at 578 nm with a 1.0-cm cell or larger is required.	A Bausch and Lomb Model Spectronic 21 was used.

Table A-6 Matrix Spike/Matrix Spike Duplicate Results for Cyanide - Plant B

Sample number	Sample conc. (µg/l)	Spike added (µg/l)	Spike result (µg/l)	% Recovery	Spike duplicate result, (µg/l)	% Recovery	RPD
OL-03	16.11	24.75	29.16	52.7	28.97	52.0	0.7

OL-03 = Treated waste sample; Sample Set No. 3.

$$\text{RPD} = 100\ (\text{spike result} - \text{spike duplicate result}) / \frac{(\text{spike result} + \text{spike duplicate result})}{2}$$

APPENDIX B

SUMMARY OF WASTE COMPOSITION DATA

Table B-1 F006 Waste Composition Data

Constituent/ parameter (units)	Concentration (source) (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)[a]	(8)[a]
BDAT Inorganics Other Than Metals (mg/kg)									
169. Cyanide (total)	<0.1-506	84.1-226	<2	-	0.1-5.8	-	<0.025-1,970	554-859	1,800-2,860
169. Cyanide (amenable)	<0.10-0.22	<1-153	<2	-	0.1	-	0.003-162	-	-
170. Fluoride	-	-	-	268	-	-	-	-	-
BDAT Metals (mg/kg)									
154. Antimony	-	-	<10	22.4	-	-	-	221-339	<6.2
155. Arsenic	-	-	2-5	<0.4	<6.24	-	-	0.353-0.797	0.48-0.76
156. Barium	0.74-85.5	-	20-45	28.8	9-57	-	-	35.8-54.0	6.39-7.92
157. Beryllium	-	-	<2	<0.1	<97.6	-	-	<0.19	<0.05
158. Cadmium	1.3-720	1,280-4,070	10-20	0.37-1.75	<11-1,320	ND-22,000	0.003-1,180	1.63-1.97	35,500-42,900
159. Total chromium	2-49,000	147-8,610	3,200-75,000	1,650-2,625	35-730	200-137,000	<0.002-290,000	622-803	4,290-5,380
160. Copper	1.4-27,400	345-28,100	90-775	1.87-135	<6-760	-	-	10,200-13,600	7,100-8,700
161. Lead	1.69-24,500	-	85-134	184-305	<6-408	-	<0.001-13,900	9.4-11.3	<6.92-9.7
162. Mercury	-	-	<1	<0.2	<0.32	-	-	<0.144-0.616	<0.137
163. Nickel	234-23,700	1,330-26,000	7,300-49,000	11.8-17	-	-	0.06-170,000	1,170-1,470	10,300-12,500
164. Selenium	-	-	<10	<0.03	<19-<23	-	-	114-167	<0.16
165. Silver	0.51-38.9	-	<2	<0.6-<1.0	-	-	-	<1.26-1.99	<0.86
166. Thallium	-	-	<10	<20	-	-	-	<6.0	<12.7
167. Vanadium	-	-	-	1.26	-	-	-	1.75-2.5	3.66-4.44
168. Zinc	8.86-90,200	611-41,200	68-3,700	2,510-3,687	<29-220	-	-	9,130-12,200	4,160-5,320
221. Hexavalent chromium	-	-	0.14-1.0	-	0.25-25.4	-	<0.001-910	-	-

Table B-1 (continued)

Constituent/ parameter (units)	Concentration (source)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)[a]	(8)[a]
Other Parameters									
Oil and grease (mg/g)	0.03-37.7	-	-	-	-	-	-	-	-
Moisture (%)	29.1-91.2	-	47.4-48.94	-	-	-	-	69.1-76.3	-
SP gravity (g/ml)			1.38-1.493	-	-	-	-	-	-
Acidity as $CaCO_3$ (mg/l)			1,412	-	-	-	-	-	-
Sulfide (mg/kg)	-	-	-	21	-	-	-	-	-
Total organic carbon (mg/kg)	-	-	<5,800	-	-	-	-	-	-

[a] The ranges presented represent six samples analyzed from the same process.

- = Not analyzed.

ND = Not detected.

References:

(1) Chemical Waste Management 1987.
(2) MRI 1987.
(3) USEPA 1986.
(4) John Deere Company 1988.
(5) Environ 1985.
(6) USEPA 1980.
(7) Versar 1986.
(8) PEI 1988.

Table B-2 F007 Waste Composition Data

Constituent/parameter (units)	Concentration (source) (1)	 (2)	 (3)	 (4)
BDAT Inorganics Other Than Metals (mg/l)				
Cyanide (amenable)	CBI	-	-	-
Cyanide (iron)[a]	CBI	-	1/0	-
Cyanide (total)	CBI	4,000-67,000	41,000	2,000-15,000
Fluoride	CBI	-	-	-
BDAT Metals (mg/l)				
Cadmium	CBI	-	-	-
Chromium (total)	CBI	-	-	-
Chromium (hexavalent)	CBI	-	-	-
Copper	CBI	-	-	-
Nickel	CBI	-	-	-
Zinc	CBI	-	-	-
Non-BDAT Metals (mg/l)				
Calcium	CBI	-	-	-
Iron	CBI	-	-	-
Magnesium	CBI	-	-	-
Manganese	CBI	-	-	-
Sodium	CBI	-	-	-
BDAT Volatiles (mg/l)				
Methanol	CBI	-	-	-
Other Parameters				
Carbonate (mg/l)	CBI	-	-	-
Total solids (%)	CBI	-	-	-
Ash (%)	CBI	-	-	-
Total suspended solids (mg/l)	CBI	-	-	-
Suspended ash (mg/l)	CBI	-	-	-
Chemical oxygen demand (mg/l)	CBI	-	-	-
pH	CBI	-	-	-
Specific gravity	CBI	-	-	-

[a] Cyanide (iron) is interpreted as a measurement of cyanide not amenable to chlorination.

- = Not analyzed.

Table B-2 (continued)

Constituent/parameter (units)	Concentration (source)				
	(5)	(5)	(5)	(5)	(6)
BDAT Inorganics Other Than Metals (mg/l)					
Cyanide (amenable)	28,200	64,200	5,700	25,600	-
Cyanide (iron)[a]	-	-	-	-	-
Cyanide (total)	30,200	66,900	8,010	27,600	20,000-25,000
Fluoride	-	-	-	-	-
BDAT Metals (mg/l)					
Cadmium	-	16,300	-	10,600	1,500
Chromium (total)	-	-	-	-	-
Chromium (hexavalent)	-	-	-	-	400
Copper	-	-	2,880	383	-
Nickel	-	-	-	-	7,000-8,000
Zinc	15,700	-	-	-	-
Non-BDAT Metals (mg/l)					
Calcium	-	-	-	-	-
Iron	-	-	-	-	-
Magnesium	-	-	-	-	-
Manganese	-	-	-	-	-
Sodium	-	-	-	-	-
BDAT Volatiles (mg/l)					
1,1-Dichloroethane	<0.002	<0.002	<0.010	0.0348	-
Methanol	-	-	-	-	-
Methylene chloride	<0.002	<0.002	0.0262	0.0324	-
Toluene	0.0137	<0.002	0.0562	0.0023	-
1,1,1-Trichloroethane	<0.002	<0.002	<0.010	0.011	-
Other Parameters					
Carbonate (mg/l)	-	-	-	-	-
Total solids (%)	-	-	-	-	-
Ash (%)	-	-	-	-	-
Total suspended solids (mg/l)	-	-	-	-	-
Suspended ash (mg/l)	-	-	-	-	-
Chemical oxygen demand (mg/l)	-	-	-	-	-
pH	-	-	-	-	-
Specific gravity	-	-	-	-	

[a] Cyanide (iron) is interpreted as a measurement of cyanide not amenable to chlorination.

- = Not analyzed.

References:

(1) USEPA 1988f.
(2) Patterson and Minear 1973.
(3) Versar 1986.
(4) USEPA 1980.
(5) MRI 1987.
(6) CyanoKEM 1987.

Table B-3 F008 Waste Composition Data

Constituent/parameter (units)	Concentration (source)				
	(1)	(2)	(2)	(2)	(3)
BDAT Inorganics Other Than Metals (mg/kg)					
Cyanide (amenable)	-	11,700	21,700	34,200	-
Cyanide (total)	64	11,900	26,600	34,900	50,000-55,000
BDAT Metals (mg/kg)					
Cadmium	-	-	13,000	-	<100
Chromium (hexavalent)	-	-	-	-	300
Copper	-	-	-	21,600	-
Lead	-	-	-	-	150-200
Nickel	-	-	-	-	300
Zinc	-	13,100	-	-	-
BDAT Volatiles (mg/kg)					
Methylene chloride	-	<1.20	<0.008	14.4	-

- = Not analyzed.

References:
(1) USEPA 1980.
(2) MRI 1987.
(3) CyanoKEM 1987.

Table B-4 F009 Waste Composition Data

Constituent/parameter (units)	Concentration (source)				
	(1)	(2)	(2)	(3)	(4)
BDAT Inorganics Other Than Metals (mg/l)					
Cyanide (amenable)	-	52,000-90,000	-	-	62,900
Cyanide (iron)[a]	-	-	100	-	-
Cyanide (total)	350,000	-	40,000	4,000-8,000	64,600
BDAT Metals (mg/l)					
Cadmium	-	-	-	-	-
Chromium (hexavalent)	-	-	-	-	-
Copper	-	19,000	-	-	-
Lead	-	-	-	-	-
Nickel	-	5,100-5,500	-	-	7,310
Non-BDAT Metals (mg/l)					
Iron	-	720-15,000	-	-	-

- = Not analyzed.

[a] Cyanide (iron) is interpreted as a measurement of cyanide not amenable to chlorination.

References:

(1) USEPA 1980.
(2) Versar 1986.
(3) Patterson and Minear 1973.
(4) MRI 1987.
(5) CyanoKEM 1987.

Table B-4 (continued)

Constituent/parameter (units)	Concentration (source)			
	(4)	(4)	(4)	(5)
BDAT Inorganics Other Than Metals (mg/l)				
Cyanide (amenable)	109,000	14,400	47,400	-
Cyanide (iron)[a]	-	-	-	-
Cyanide (total)	115,000	14,500	52,500	40,000-45,000
BDAT Metals (mg/l)				
Cadmium	388	-	-	200
Chromium (hexavalent)	-	-	-	<100
Copper	-	6,990	-	-
Lead	-	-	-	200
Nickel	-	-	7,510	12,000-15,000
Non-BDAT Metals (mg/l)				
Iron	-	-	-	-

- = Not analyzed.

[a] Cyanide (iron) is interpreted as a measurement of cyanide not amenable to chlorination.

References:
(1) USEPA 1980.
(2) Versar 1986.
(3) Patterson and Minear 1973.
(4) MRI 1987.
(5) CyanoKEM 1987.

Table B-5 F010 Waste Composition Data

Constituent/parameter (units)	Concentration (source) (1)	 (2)
BDAT Inorganics Other Than Metals (mg/kg)		
Cyanide (total)	8,530	22,000
Other Parameters		
Heat content (Btu/lb)	-	5,000
Water (%)	-	ND
Oil and grease	-	>5 [a]

---

[a] Data submitted to the Agency did not report an oil and grease concentration. However, these waste composition data represent a waste that was incinerated, and CyanoKEM indicated that a waste must have oil and grease concentration of at least 5 percent in order to be incinerated.

- = Not analyzed.
ND = Not detected.

References:
(1) USEPA 1980.
(2) CyanoKEM 1988.

Table B-6 F011 Waste Composition Data

Constituent/parameter (units)	Concentration (source)			
	(1)	(2)	(2)	(3)
BDAT Inorganics Other Than Metals (mg/l)				
Cyanide (amenable)	I	-	34,000-35,000	-
Cyanide (total)	5,350[a]	10,000-12,000	-	85,000-90,000
Fluoride	5.55	-	-	-
BDAT Metals (mg/l)				
Antimony	0.029	-	-	-
Barium	1.0	-	-	-
Cadmium	0.01	-	-	<100
Chromium (hexavalent)	<0.01	-	-	1,000-1,500
Chromium (total)	5.42	-	-	-
Copper	1.03	-	-	-
Lead	1.1	-	-	500-1,000
Nickel	2.88	-	-	300
Silver	0.0072	-	-	-
Vanadium	0.156	-	-	-
Zinc	0.338	-	-	-
Non-BDAT Metals (mg/l)				
Iron	27.8	-	-	-
Potassium	18,500	-	-	-
Sodium	32,200	-	-	-
Non-BDAT Inorganics Other Than Metals (mg/l)				
Carbonate	87,000	-	-	-
Chloride	21,300	-	-	-
Sulfate	90.5	-	-	-
Other Parameters				
Total solids (%)	19.7	-	-	-
Total suspended solids (%)	3.84	-	-	-
Chemical oxygen demand (mg/l)	7,140	-	-	-
Total organic carbon (mg/l)	19,500	-	-	-
Oil and grease (mg/l)	11.0	-	-	-

I = Analytical interference. Analysis of partially treated sample indicates that this value is <5120 mg/l.

- = Not analyzed.

[a] The concentration of total cyanide referred to here is based on testing of a waste that had been dissolved in aqueous solution for electrolytic treatment. The concentration of total cyanide in the solid waste treated was approximately 90,000 mg/kg, and the concentration of amenable cyanide was <2.5 mg/kg.

References:

(1) USEPA 1988e.

(2) Environ 1985.

(3) CyanoKEM 1987.

Table B-7 F012 Waste Composition Data

Constituent/parameter (units)	Concentration (source)				
	(1)	(2)	(2)	(3)	(4)
BDAT Inorganics Other Than Metals (mg/kg)					
Cyanide (total)	21	26,800	8,400	1,500	60,000-65,000
Fluoride	6.5	-	-	-	-
BDAT Metals (mg/kg)					
Barium	98	-	-	-	-
Cadmium	5.31	-	-	-	<100
Chromium (hexavalent)	-	-	-	-	350
Chromium (total)	11	-	-	-	-
Copper	307	-	-	-	-
Lead	28	-	-	-	500-600
Nickel	758	-	-	-	400-500
Silver	0.73	-	-	-	-
Vanadium	6.7	-	-	-	-
Zinc	54	-	-	-	-
BDAT Volatile Organics (μg/kg)					
Acetone	250	-	-	-	-
Chloroform	110	-	-	-	-
Methylene chloride	11	-	-	-	-
Toluene	28	-	-	-	-
BDAT Semivolatile Organics (μg/kg)					
Bis(2-ethylhexyl) phthalate	1,600	-	-	-	-
PCBs (μg/kg)					
Aroclor 1254	35	-	-	-	-
Non-BDAT Metals (mg/kg)					
Iron	2,880	-	-	-	-
Sodium	1,276	-	-	-	-
Non-BDAT Inorganics Other Than Metals (mg/kg)					
Chloride	992	-	-	-	-
Sulfate	6,900	-	-	-	-

Table B-7 (continued)

Constituent/parameter (units)	Concentration (source)				
	(1)	(2)	(2)	(3)	(4)
Other Parameters					
Total solids (%)	60.5	-	-	-	-
Total organic carbon (mg/kg)	540	-	-	-	-
Oil and grease (mg/kg)	432	-	-	-	-
pH	-	-	-	10.5-11.0	-

- = Not analyzed.

References:

(1) USEPA 1988e.

(2) USEPA 1980.

(3) Environ 1985.

(4) CyanoKEM 1987.

Table B-8 F019 Waste Composition Data

Constituent/parameter (units)	Concentration (source) (1)	(1)	(2)	(3)
BDAT Inorganics Other Than Metals (mg/kg)				
Cyanide (total)	7.76	3.93	-	<0.001-3,824
Cyanide (amenable)	7.76	ND	-	-
BDAT Metals (mg/kg)				
Cadmium	0.212	0.288	-	<0.01-28
Chromium (hexavalent)	-	-	-	<0.04-25
Chromium (total)	6,540	150	289	14-90,000
Copper	-	-	68	-
Nickel	3.25	3.08	1,275	<4-47
Other Parameters				
Total solids	-	-	-	2-35

- = Not analyzed.
ND = Concentration reported as "zero."

References:
(1) MRI 1987.
(2) AES 1981.
(3) Versar 1986.

APPENDIX C

ANALYTICAL METHOD FOR MEASUREMENT OF THERMAL CONDUCTIVITY

The comparative method of measuring thermal conductivity has been proposed as an ASTM test method under the name "Guarded, Comparative, Longitudinal Heat Flow Technique". A thermal heat flow circuit is used which is the analog of an electrical circuit with resistances in series. A reference material is chosen to have a thermal conductivity close to that estimated for the sample. Reference standards (also known as heat meters) having the same cross-sectional dimensions as the sample are placed above and below the sample. An upper heater, a lower heater, and a heat sink are added to the "stack" to complete the heat flow circuit. See Figure 1.

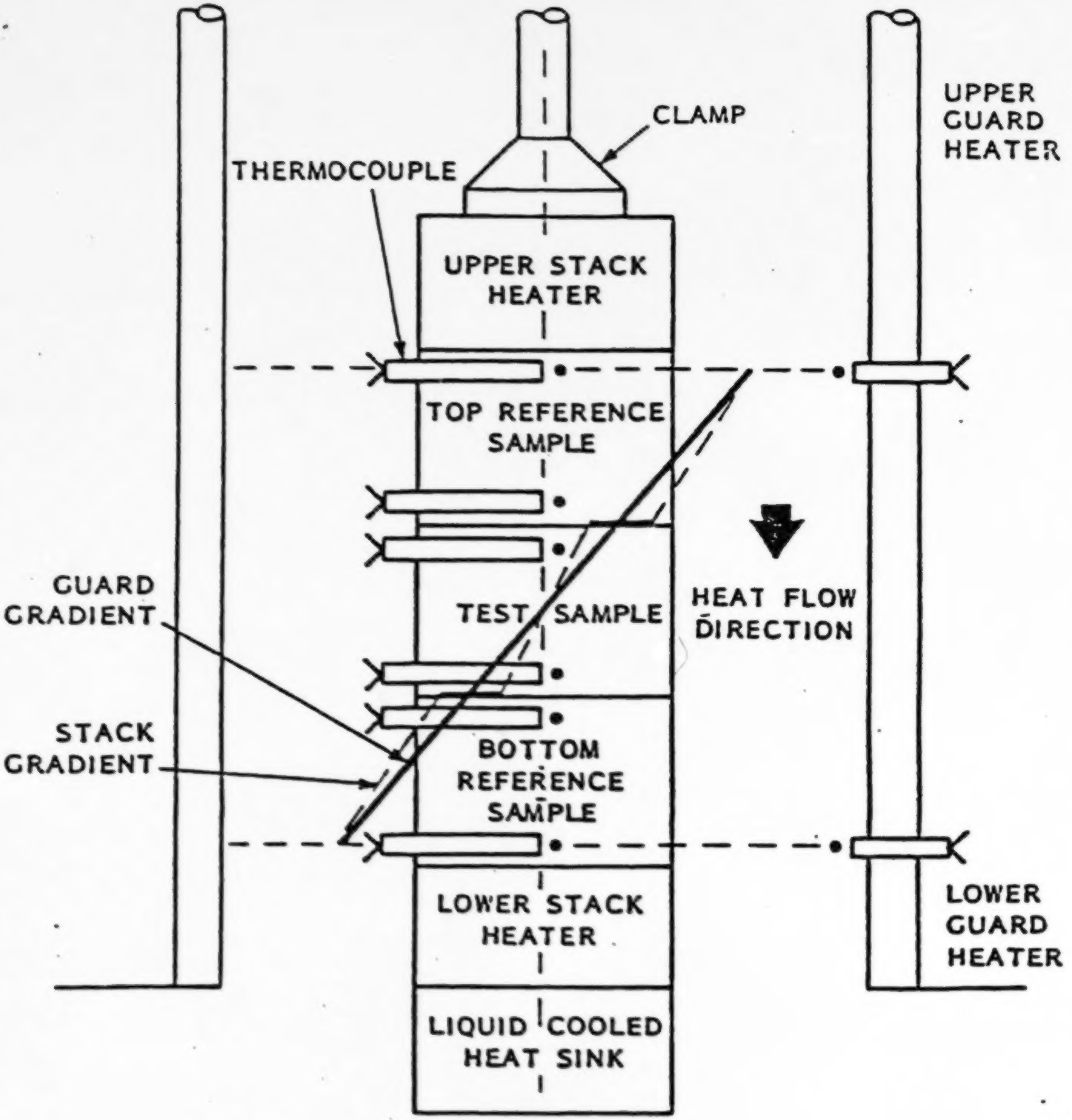
UPPER GUARD HEATER
CLAMP
THERMOCOUPLE
UPPER STACK HEATER
TOP REFERENCE SAMPLE
GUARD GRADIENT
TEST SAMPLE
HEAT FLOW DIRECTION
STACK GRADIENT
BOTTOM REFERENCE SAMPLE
LOWER STACK HEATER
LOWER GUARD HEATER
LIQUID COOLED HEAT SINK

Figure 1.

SCHEMATIC DIAGRAM OF THE COMPARATIVE METHOD

The temperature gradients (analogous to potential differences) along the stack are measured with type K (chromel/alumel) thermocouples placed at known separations. The thermocouples are placed into holes or grooves in the references and also in the sample whenever the sample is thick enough to accommodate them.

For molten samples, pastes, greases, and other materials that must be contained, the material is placed into a cell consisting of a top and bottom of Pyrex 7740 and a containment ring of marinite. The sample is 2 inch in diameter and .5 inch thick. Thermocouples are not placed into the sample but rather the temperatures measured in the Pyrex are extrapolated to give the temperature at the top and bottom surfaces of the sample material. The Pyrex disks also serve as the thermal conductivity reference material.

The stack is clamped with a reproducible load to insure intimate contact between the components. In order to produce a linear flow of heat down the stack and reduce the amount of heat that flows radially, a guard tube is placed around the stack and the intervening space is filled with insulating grains or powder. The temperature gradient in the guard is matched to that in the stack to further reduce radial heat flow.

The comparative method is a steady state method of measuring thermal conductivity. When equilibrium is reached the heat flux (analogous to current flow) down the stack can be determined from the references. The heat into the sample is given by

$$Q_{in} = \lambda_{top}(dT/dx)_{top}$$

and the heat out of the sample is given by

$$Q_{out} = \lambda_{bottom}(dT/dx)_{bottom}$$

where

λ = thermal conductivity

dT/dx = temperature gradient

and top refers to the upper reference while bottom refers to the lower reference. If the heat was confined to flow just down the stack, then Q_{in} and Q_{out} would be equal.. If Q_{in} and Q_{out} are in reasonable agreement, the average heat flow is calculated from

$$Q = (Q_{in} + Q_{out})/2$$

The sample thermal conductivity is then found from

$$\lambda_{sample} = Q/(dT/dx)_{sample}$$

The result for the K102 Activated Charcoal Waste tested here is given in Table 1. The sample was held at an average temperature of 42C with a 53C temperature drop across the sample for approximately 20 hours before the temperature profile became steady and the conductivity measured. At the conclusion of the test it appeared that some "drying" of the sample had occurred.